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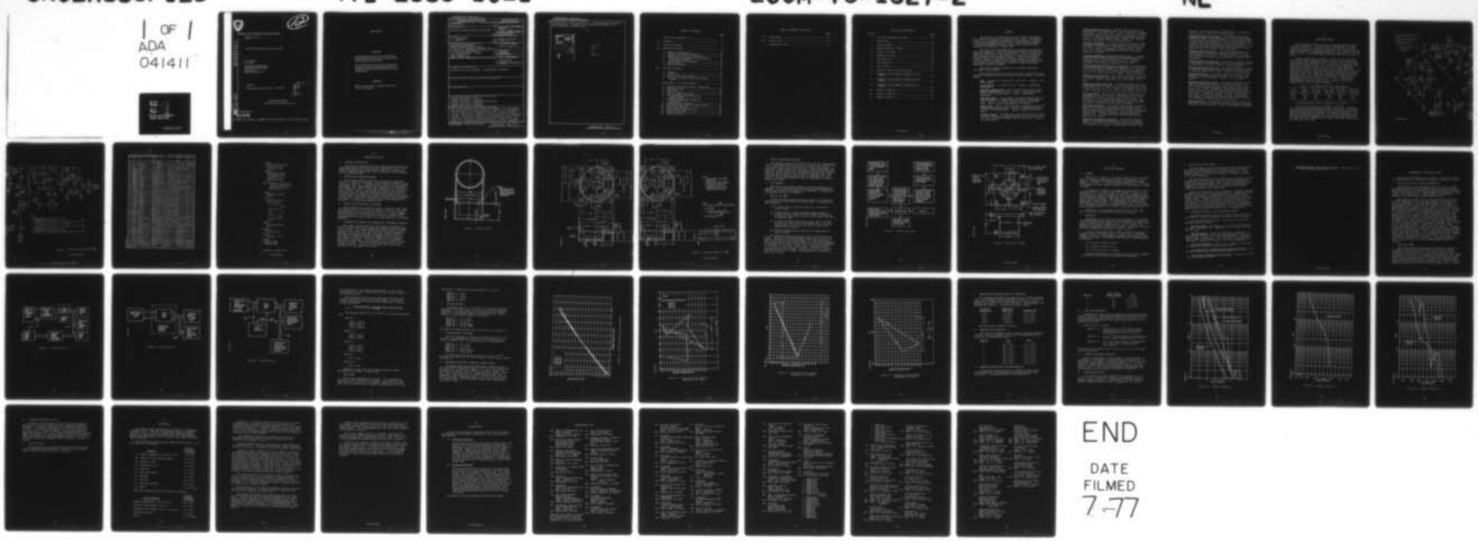

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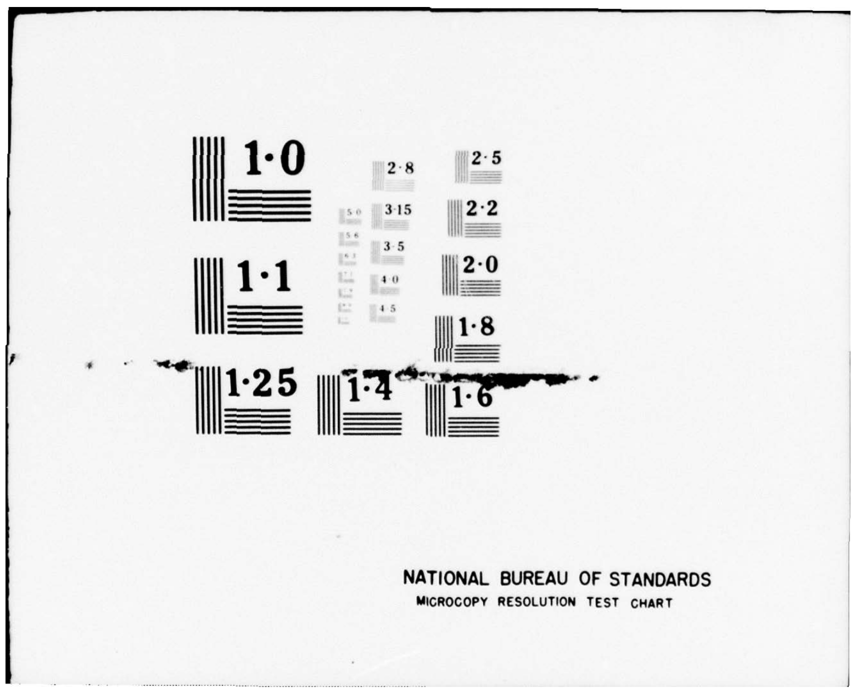
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NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

12

Research and Development Technical Report

ECOM- 75-1327-2



# TACTICAL MINIATURE CRYSTAL OSCILLATOR

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THE BENDIX CORPORATION
COMMUNICATIONS DIVISION
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JUNE 1977

Semiannual Report 15 October 1975 – 15 June 1976



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|---|---|---|
| 1. REPORT NUMBER<br>18 ECOM-75-1327-2 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER<br>9 Semiannual rept. |
| 4. TITLE (and Subtitle)<br>6 TACTICAL MINIATURE CRYSTAL OSCILLATOR | | 5. TYPE OF REPORT & PERIOD COVERED<br>INTERIM<br>15 Oct 75 ~~to~~ - 15 June 76 |
| | | 6. PERFORMING ORG. REPORT NUMBER<br>14 471-2583-1021 |
| 7. AUTHOR(s)<br>10 H. M. GREENHOUSE<br>R. L. McGILL | | 8. CONTRACT OR GRANT NUMBER(s)<br>15 DAAB07-75-C-1327 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>THE BENDIX CORPORATION<br>~~BENDIX~~ COMMUNICATIONS DIVISION<br>E. JOPPA RD., BALTIMORE, MARYLAND 21204 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>672705 11 H94 F2 01 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>U.S. ARMY ELECTRONICS COMMAND<br>FORT MONMOUTH, NJ<br>ATTN: DRSEL-TL-MF | | 12. REPORT DATE<br>11 JUNE 1977 |
| | | 13. NUMBER OF PAGES<br>53 12 44p. |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>UNCLASSIFIED |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Crystal Oscillator, 5 MHz
Crystal Oscillator, Low Power
Crystal Oscillator, Temperature Controlled
Crystal Oscillator, Miniature
Crystal Oscillator, Precision

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the further development of a fast warmup Tactical Miniature Crystal Oscillator (TMXO). The intended use for this TMXO is as a reference frequency source in advanced tactical communications systems and in time ordered navigational systems. The present effort is a continuation by the authors of a previous study which defined particular problem areas. The TMXO is an evacuated enclosure containing a thermal insulating pedestal, a vacuum sealed hybrid microcircuit and a thermally over



402895

isotropic back filled crystal unit. Both packages are supported by the pedestal. Changes in the design and performance of delivered models are described.

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# PURPOSE

The objective of this program is the further development of a Tactical Miniature Crystal Oscillator (TMXO). The present effort is a continuation of research and development conducted by the Bendix Communications Division, under contracts DAAB07-71-C-0265 and DAAB07-73-C-0199. This earlier work has been reported in ECOM-0265F and ECOM-0199F.

The tasks to be performed during the present contract fall into two categories. The first category contains the unsolved problems remaining from the previous work. This includes excess power aging (because of the inability to maintain a vacuum inside the TMXO), and frequency recovery. The latter is most probably related to the crystal and its package. The severity of this problem is expected to be greatly diminished when a new type ceramic crystal enclosure (presently under development elsewhere) becomes available.

The second category consists of new and/or additional performance requirements.

The required characteristics of the TMXO, together with the achieved characteristics at the onset of this contract, are given below.

<u>Size</u>. Volume not to exceed one cubic inch. Status - 1.08 cubic inches.

<u>Input Voltage</u>. 12 volts DC, ±5%. Status - requirement satisfied.

<u>Available Warmup Power</u>. Not to exceed 10.0 watts at any ambient temperature (-54°C to +75°C), during the allowed warmup time (three minutes). Status - requirement satisfied.

<u>Operating Power</u>. After warmup, the maximum power input to the TMXO shall not exceed 250 milliwatts at any temperature. Status - 1.7 watts without a vacuum inside the TMXO. With a vacuum, 250 milliwatts at -40°C.

<u>Power Aging</u>. Aging of the TMXO power consumption shall not exceed 1 percent per month. Status - unable to maintain low power (250 milliwatts). Aging is 680 percent in one hour.

<u>Voltage Control</u>. The TMXO shall have provision for voltage control, allowing a frequency deviation no less than $1.0 \times 10^{-7}$ for a DC voltage change from 0 to +10 volts. Status - new requirement.

Ambient Temperature Range. The TMXO shall meet all requirements of this specification over the ambient temperature range of -54°C to +75°C. Status - this is an extended temperature range beyond the previous requirement of -40°C to +75°C. This new range presents no additional problems, except, the maximum operating power (now at 54°C instead of -40°C) may have to rise to 280 milliwatts.

Frequency Adjustment. A control shall be provided so that the output frequency may be conveniently and uncritically adjusted to 5.115 MHz $\pm 1 \times 10^{-10}$ with a minimum range of $\pm 1 \times 10^{-8}$. Status - requirement satisfied using a ten turn 0-100 kilohm potentiometer from one of the TMXO's terminals to ground.

Frequency/Temperature Stability (Steady State). The maximum permissible frequency deviation over the temperature range of -54°C to +75°C shall be $\pm 1 \times 10^{-8}$. Status - requirement satisfied with TMXO evacuated. When not evacuated, the frequency variation is $\pm 2 \times 10^{-7}$.

Frequency/Temperature Stability (Transient). The frequency of the TMXO shall not change more than $\pm 1 \times 10^{-8}$ from its initial value when subjected to a positive 10°C amplitude, at a rate of 1°C/min., air temperature ramp starting at -40°C, -5°C, +30°C, and +65°C. Status - new requirements.

Frequency/Load Stability. The maximum frequency deviation for a load variation of 50 ohms +10%, +20° phase, shall be $\pm 1 \times 10^{-9}$. Status - typically $\pm 1 \times 10^{-9}$, worst is $\pm 3 \times 10^{-9}$.

Frequency/Voltage Stability. The maximum permissible frequency deviation for a supply voltage variation of 12 volts DC $\pm 5\%$ shall be $\pm 1 \times 10^{-9}$. Status - the typical value for a +5% voltage is $+9 \times 10^{-10}$. For a -5% voltage it is $-1.5 \times 10^{-9}$. The best is $\pm 4 \times 10^{-10}$, and the worst is $\pm 3 \times 10^{-9}$.

Frequency Aging. Aging of the TMXO output frequency shall not exceed $2 \times 10^{-10}$ per week, operating, after a 30 day stabilization period. Status - aging varied from $-3 \times 10^{-9}$/day to $-7 \times 10^{-8}$/day, depending upon the unit. The new crystal/ceramic enclosure (presently under development elsewhere) is expected to meet this requirement.

Short Term Stability. The maximum RMS frequency deviation shall be $\pm 1 \times 10^{-11}$ for averaging times ranging from 1 second to 20 minutes, under conditions of input voltage and ambient temperature controlled to $\pm 1$ millivolt and $\pm 0.1$°C, respectively. Status - dependent upon the individual crystal unit. For the good ones, the RMS deviation was less than $\pm 3 \times 10^{-11}$.

Frequency Acceleration Stability. The maximum frequency change of the TMXO measured during static acceleration shall be less than $5 \times 10^{-10}$/g when tested in accordance with Method 513, Procedure II (helicopter category) MIL-

STD-810B. Permanent frequency change shall be no greater than $\pm 1 \times 10^{-9}$. Status - new requirement.

Frequency/Vibration Stability. The maximum permissible frequency change of the TMXO measured during and following vibration without isolators shall be $\pm 1 \times 10^{-9}$ when tested in accordance with Method 514, curve M, MIL-STD-810B. The frequency deviation represented by the modulation side bands at the vibration frequency shall not exceed $5 \times 10^{-10}$ times the peak acceleration level specified for that frequency by curve M. Status - new requirement.

Frequency/Shock Stability. The maximum permissible frequency change of the TMXO following a shock of 50 g, 11 milliseconds, shall be $\pm 1 \times 10^{-9}$ when tested in accordance with method 213 condition G, MIL-STD-202D. Status - new requirement.

Frequency/Attitude Stability. The maximum frequency change of the TMXO for a 90 $\pm 5°$ attitude change in any axis shall be less than $\pm 5 \times 10^{-10}$. Status - new requirement.

Frequency/Altitude Stability. The maximum frequency change of the TMXO following an altitude change from sea level to 10,000 feet shall be $\pm 1 \times 10^{-9}$. Status - new requirement.

Stabilization Time. Following application of power, the frequency of the TMXO shall be within $\pm 1 \times 10^{-8}$ of final frequency in three minutes. Status - 3-1/4 minutes at -45°C.

Frequency Recovery at -40°C. The output frequency of the TMXO after warmup during each turn-on period for a five cycle frequency recovery test, shall remain within $\pm 3 \times 10^{-9}$ of the frequency measured on the first cycle. Each cycle shall consist of complete frequency stabilization during turn-on, followed by complete thermal stabilization after power is removed. Status - typical value is $\pm 4 \times 10^{-8}$ and is crystal and/or mount related. Considerable improvement is expected with the new type ceramic crystal unit (presently under development elsewhere).

Output Voltage. A minimum of 0.125 volts RMS at the 5.115 MHz output frequency shall be available across an external resistive load of 50 ohms. Status - requirement satisfied.

# II

## ELECTRONIC DESIGN

The electrical schematic, used in the deliverable models, is shown in Figure 1. It is the same as presented in the previous report with the exception of the values of R27 and the external temperature setting potentiometer. The value of R27 has been changed from an unspecified select by test value, to (RT1 at 90°C) - 22 kΩ. The potentiometer has been changed from 20 kΩ to 50 kΩ.

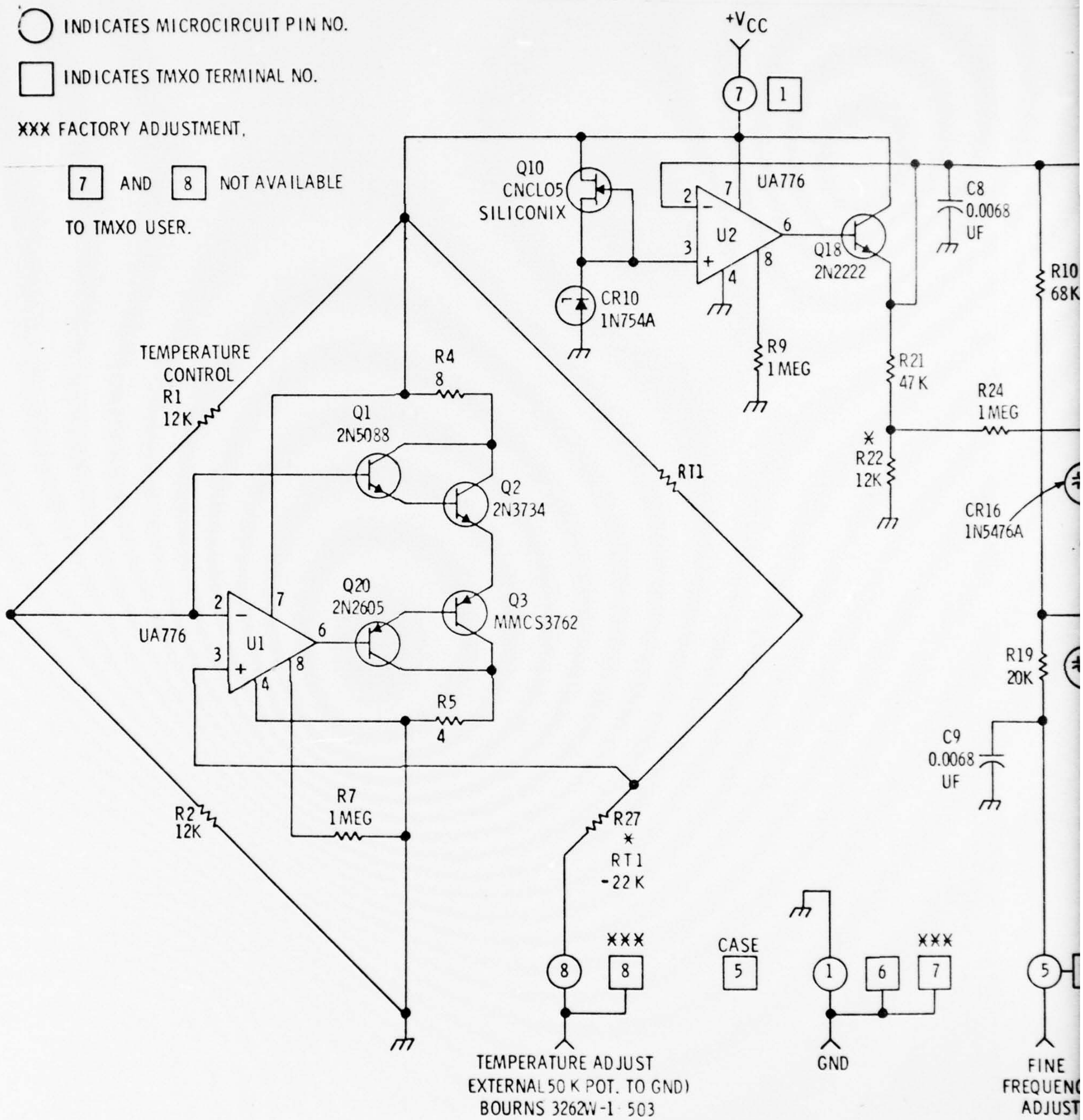
These changes were necessary to allow for the resistance tolerance of the thermistor at 90°C, and for the ±5°C variation in the upper turn temperature of the crystal. The value of the thermistor at 90°C is 54 kΩ, ±10%. The minimum thermistor value due to its tolerance is 49.6 kΩ at 90°C. If the upper turn temperature of the crystal is a 95°C, the minimum thermistor value will be 42 kΩ. The maximum thermistor value will be a +10% tolerance thermistor, when the upper turn temperature is +85°C. This value is 73 kΩ. Therefore, allowing for a ±10% thermistor tolerance, and a ±5°C upper turn temperature tolerance, the thermistor range will be from 42 kΩ to 73 kΩ. The minimum potentiometer value is 73 kΩ - 42 kΩ = 31 kΩ. Using a 50 kΩ potentiometer, the near optimum value of R27 = RT - 22 kΩ, measuring RT at 90°C. Refer to Table 1.

TABLE 1. THE RANGE OF R27 AND POTENTIOMETER

| RT at 90°C | R27 (RT-22k) | RT with 85°C Xle | Pot. with 85°C Xle | RT with 95°C Xle | Pot. with 95°C Xle |
|---|---|---|---|---|---|
| 60KΩ | 38KΩ | 73KΩ | 35KΩ | 51KΩ | 13KΩ |
| 48KΩ | 26KΩ | 58KΩ | 32KΩ | 42KΩ | 16KΩ |

An up-dated parts list is tabulated in Figure 2.

To test the microcircuit (without a crystal), a microcircuit test fixture was fabricated. With this fixture, the sealed and unsealed microcircuit was tested in conjunction with a temperature controlled test crystal. This crystal was kept at its upper turn temperature being part of a TMXO configuration with the oscillator disconnected. The crystal leads were brought to two TMXO terminals, where short (2 inch) rigid leads went to the microcircuit under test.



INDICATES MICROCIRCUIT PIN NO.
INDICATES TMXO TERMINAL NO.
XXX FACTORY ADJUSTMENT.
7 AND 8 NOT AVAILABLE TO TMXO USER.
+VCC
UA776
Q10 CNCL05 SILICONIX
CR10 1N754A
U2
Q18 2N2222
C8 0.0068 UF
R10 68K
R9 1MEG
R21 47K
R24 1MEG
R22 12K
CR16 1N5476A
TEMPERATURE CONTROL
R1 12K
R4 8
Q1 2N5088
Q2 2N3734
RT1
Q20 2N2605
Q3 MMCS3762
UA776
U1
R5 4
R19 20K
C9 0.0068 UF
R2 12K
R7 1MEG
R27
RT1 -22K
CASE
GND
TEMPERATURE ADJUST EXTERNAL 50 K POT. TO GND)
BOURNS 3262W-1-503
FINE FREQUENC
ADJUST
0-100K
10 TURN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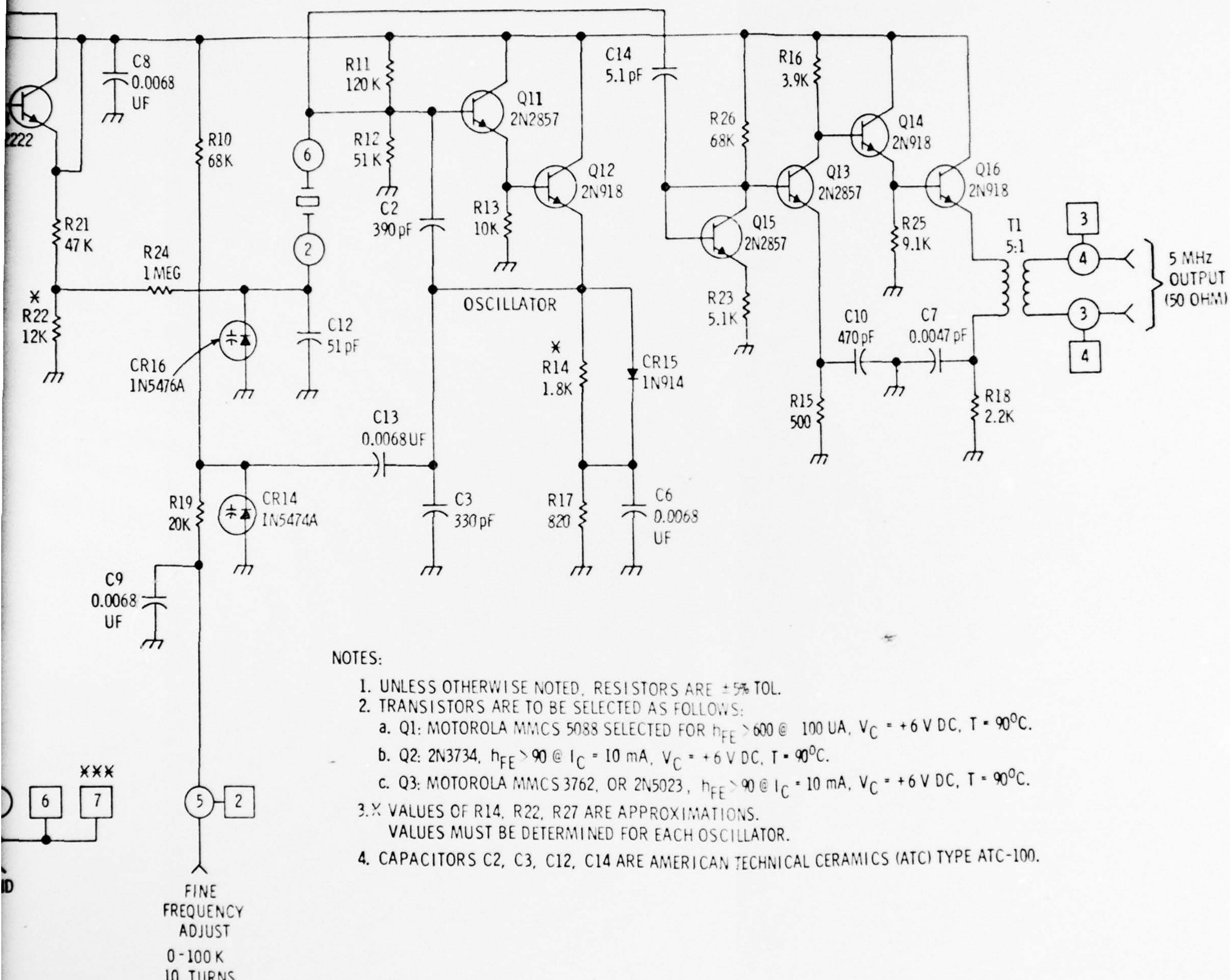


NOTES:

1. UNLESS OTHERWISE NOTED, RESISTORS ARE ±5% TOL.
2. TRANSISTORS ARE TO BE SELECTED AS FOLLOWS:
   a. Q1: MOTOROLA MMCS 5088 SELECTED FOR $h_{FE} > 600$ @ 100 UA, $V_C = +6$ V DC, T = 90°C.
   b. Q2: 2N3734, $h_{FE} > 90$ @ $I_C = 10$ mA, $V_C = +6$ V DC, T = 90°C.
   c. Q3: MOTOROLA MMCS 3762, OR 2N5023, $h_{FE} > 90$ @ $I_C = 10$ mA, $V_C = +6$ V DC, T = 90°C.
3. ⁎ VALUES OF R14, R22, R27 ARE APPROXIMATIONS. VALUES MUST BE DETERMINED FOR EACH OSCILLATOR.
4. CAPACITORS C2, C3, C12, C14 ARE AMERICAN TECHNICAL CERAMICS (ATC) TYPE ATC-100.

Figure 1. Electrical Schematic of TMXO



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| QTY | IDENT | MANUFACTURER | SIZE | DESCRIPTION | PART NO. | NOTES |
|---|---|---|---|---|---|---|
| | | | | | | |
| 1 | | | — | PKG COVER, BENDIX No SK1140-100-1 | | NOTE 5 |
| — | | | DA=1 | GOLD WIRE | | |
| — | — | EPOTEK | — | EPOXY INSULATING | H61 | NOTE 7,8 |
| — | — | EPOTEK | — | EPOXY SILVER CONDUCTING | H31 | NOTE 6 |
| 1 | — | | — | MICROCIRCUIT PKG. BENDIX No. SK1140-100-2 | | NOTE 6 |
| — | S-1 | KESTER | — | SOLDER 95% Sn-5% Sb SOL 235-232°C | 995 | |
| 1 | PtAu | BENDIX | 50x50 | PLATINUM-GOLD ON CERAMIC, NEAR PIN 2 | | |
| 2 | BeOAu-7,-9 | ANY | 40x20x12 | GOLD ON BeO, UNDER Q15, UNDER Q13 | | |
| 1 | BeOAu-6 | ANY | 80x40x12 | GOLD ON BeO, UNDER CR16 | | |
| 1 | BeOAu-5 | ANY | 60x40x12 | GOLD ON BeO, UNDER CR14 | | |
| 2 | BeOAu-3,-8 | ANY | 60x20x12 | GOLD ON BeO, UNDER Q18, UNDER Q14&Q16 | | |
| 2 | BeOAu-2,-4 | ANY | 50x30x12 | GOLD ON BeO, UNDER Q10, UNDER Q11&Q12 | | |
| 1 | BeOAu-1 | BENDIX | 110x60x12 | GOLD ON BeO 2 CUT SPACES-5MILS EACH, UNDER Q1,7,9, 30&RT1 | | NOTE 1 |
| 1 | BeO-2 | ANY | 55x55x12 | PLAIN BeO UNDER C14 | | |
| 1 | BeO-1 | ANY | 110x110x12 | PLAIN BeO UNDER C2 | | |
| 1 | GAuT-5 | BENDIX | 70x20x6 | GOLD TRACK ON GLASS | | |
| 3 | GAuT-2,3,4 | BENDIX | 100x20x6 | GOLD TRACK ON GLASS, AT PIN 7, PIN 1, NEAR R5 | | |
| 1 | GAuT-1 | BENDIX | 75x20x6 | GOLD TRACKS ON GLASS BETWEEN U1 & U2 | | |
| 1 | G3 | BENDIX | 50x50x6 | PLAIN GLASS UNDER C3 | | |
| 1 | GAu-6 | BENDIX | 150x20x6 | GOLD ON GLASS, NEAR PIN 8 | | |
| 2 | G1, G2 | BENDIX | 65x50x6 | PLAIN GLASS UNDER U1 & U2. | | |
| 2 | GAu-4,-5 | BENDIX | 100x20x6 | GOLD ON GLASS, REG NEAR R12 | BETWEEN R21 & R22 | |
| 3 | GAu-1,-2,-3 | BENDIX | 20x20x6 | GOLD ON GLASS, NEAR U2, ON | C2, ON C9 | |
| 1 | R23 | BENDIX | 27x6 | THIN FILM RESISTOR 5.1KΩ±5% | | |
| 1 | R100 | BENDIX | 34x6 | THIN FILM RESISTOR 22.5KΩ±5% | | |
| 1 | R27 | BENDIX | 40x6 | THIN FILM RESISTOR (RT) AT 90°C-22K | | NOTE 4 |
| 1 | R25 | BENDIX | 21x6 | THIN FILM RESISTOR 9.1KΩ±5% | | |
| 1 | R22 | BENDIX | | THIN FILM RESISTOR VALUE TO | BE DETERMINED | NOTE 3 |
| 1 | R21 | BENDIX | 60x6 | THIN FILM RESISTOR 47KΩ±5% | | |
| 1 | R19 | BENDIX | 34x16 | THIN FILM RESISTOR 20KΩ±5% | | |
| 1 | R18 | BENDIX | 20x18 | THIN FILM RESISTOR 2.2KΩ±5% | | |
| 1 | R17 | BENDIX | 20x26 | THIN FILM RESISTOR 820Ω±5% | | |
| 1 | R16 | BENDIX | 27x16 | THIN FILM RESISTOR 3.9KΩ±5% | | |
| 1 | R15 | BENDIX | 20x22 | THIN FILM RESISTOR 500Ω±5% | | |
| 1 | R14C | BENDIX | 27x16 | THIN FILM RESISTOR 4KΩ±5% | | |
| 1 | R14B | BENDIX | 21x16 | THIN FILM RESISTOR 3KΩ±5% | | |
| 1 | R14A | BENDIX | 20x18 | THIN FILM RESISTOR 2KΩ±5% | | |
| 1 | R13 | BENDIX | 21x16 | THIN FILM RESISTOR 10KΩ±5% | | |
| 1 | R12 | BENDIX | 60x16 | THIN FILM RESISTOR 51KΩ±5% | | |
| 1 | R11 | BENDIX | 50x50 | THICK FILM RESISTOR 20KΩ±5% | | |
| 2 | R10, 26 | BENDIX | 60x16 | THIN FILM RESISTOR 68KΩ±5% | | |
| 3 | R7, 9, 24 | BENDIX | 50x50 | THICK FILM RESISTOR 1MEG±10% | | |
| 3 | R5A, 5B, 5C | BENDIX | 50x50 | THICK FILM RESISTOR 12Ω±10% | | |
| 3 | R4A, 4B, 4C | BENDIX | 50x50 | THICK FILM RESISTOR 24Ω±10% | | |
| 2 | R1, R2 | BENDIX | 27x16 | THIN FILM RESISTOR 12KΩ±5% | | |
| 1 | C14 | AMER TECH CER | 55 CUBE | CAPACITOR 5.1 pf ±.25 pf | ATC-100A5R1-C-C | NOTE 8 |
| 1 | C12 | AMER. TECH. CER | 55 CUBE | CAPACITOR 51 pf ±10% | ATC-100A510KC | |
| 1 | C10 | ANY | 50x50x30 | CAPACITOR CHIP 470 pf ±10%, K200 | | |
| 1 | C7 | ANY | 50x50x30 | CAPACITOR CHIP .0047 mf ±10%, K1200 | | |
| 4 | C6,8,9,13 | ANY | 50x50x30 | CAPACITOR CHIP .0068 mf ±20%, K1200 | | NOTE 8 (C13) |
| 1 | C3 | AMER TECH CER | 110 CUBE | CAPACITOR 330 pf ±10% | ATC-100B331KC | |
| 1 | C2 | AMER. TECH CER. | 110 CUBE | CAPACITOR, 39 pf ±5% | ATC-100B391JC | NOTE 8 |
| 1 | T1 | BENDIX (WOUND) | | TRANSFORMER 5:1, 60 TURNS PRI. 12 TURNS SEC. | | NOTE 2,7 |
| 1 | RT1 | NAT. LEAD | 30x30 | THERMISTOR CHIP, BENDIX No. 4032655-0701 | | |
| 1 | CR16 | MOT. | 40x40 | VARACTOR DIODE CHIP | 1N5476A | |
| 1 | CR15 | ANY | 15x15 | DIODE CHIP | 1N914 | |
| 1 | CR14 | MOT. | 37x37 | VARACTOR DIODE CHIP | 1N5474A | |
| 1 | CR10 | MOT. | 25x25 | ZENER DIODE CHIP | 1N754A | |
| 2 | U1, U2 | FAIR. | 50x65 | OP. AMP. CHIP | μA776 | |
| 1 | Q20 | NAT. OR OTHER | 18x18 | TRANSISTOR CHIP | 2N2605 | |
| 1 | Q18 | NAT. OR OTHER | 18x18 | TRANSISTOR CHIP | 2N2222 | |
| 3 | Q12, 14, 16 | NAT. OR OTHER | 15x15 | TRANSISTOR CHIP | 2N918 | |
| 3 | Q11, 13, 15 | NAT. OR MOT. | 15x15 | TRANSISTOR CHIP | 2N[illegible] | |
| 1 | Q10 | SILICONIX | 30x30 | FET CURRENT LIMITING CHIP | CNC[illegible] | |
| 1 | Q3 | MOT. | 29x20 | TRANSISTOR CHIP | MMCS 3762 | NOTE 1 |
| 1 | Q2 | NAT. OR MOT. | 33x27 | TRANSISTOR CHIP | 2N3734 | NOTE 1 |
| 1 | Q1 | NAT. OR MOT. | 18x18 | TRANSISTOR CHIP | 2N5088 | |
| QTY REQD -0501 | CODE IDENT NO. | PART OR IDENTIFYING NUMBER | SIZE (MIL.) | NOMENCLATURE OR DESCRIPTION | SPECIFICATION | NOTES & REF DESIGNATIONS |
| | PARTS LIST | | | | | |

002-1021-002

NOTE 1:

SELECT Q2 AND Q3, EACH TO HAVE $h_{FE} > 90$; AT $I_C = 10$ mA. +6 VOLTS AND AT 90°C. EUTECTICALLY BOND Q2 AND Q3 TO B.C.Au-1.

NOTE 2:

TRANSFORMER WOUND ON FERITE TOROID. IND. GEN. Q1 MATERIAL, SHAPE CF-120, 155 O.D. 88 ID, 55 H (mils), $K = L/N^2 = 0.018$. WIRE, ESSEX No. 38 SINGLE CLAD POLLY THERMOLEX 200.

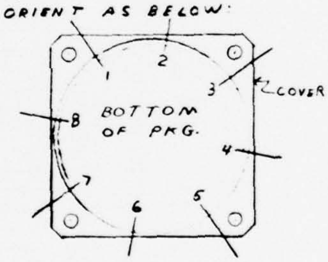
NOTE 3: PRELIMINARY WIRING FOR DETERMINING THE VALUE OF R22. WIRE AS ON RIGHT, LEAVING THE WIRE BETWEEN R22 AND GAu-5 OUT. DO NOT SEAL. R22 IS ± 0.5%

NOTE 4:

MAKE R27 = RT1 − 22KΩ USE MEASURED VALUE OF RT1 AT 90°C.

NOTE 5:

ORIENTATION OF COVER TO PKG. IS SPECIFIC ORIENT AS BELOW:




SOLDER PKG TO COVER USING SOLDER S-1.

NOTE 6

PUT ALL PARTS (EXCEPT Q2, Q3, T1, C2, C13 & C14) DOWN WITH EPOXY H 31.

NOTE 7

SECURE T1 IN PLACE WITH EPOXY H-61.

NOTE 8

PUT C2, C13 AND C14 DOWN WITH H61

NOTE 9:

SELECT Q1 TO HAVE $h_{FE} > 600$, AT $I_C = 100\mu A$. +6 VOLTS AND AT 90°C.

Figure 2. Parts List

## III

## MECHANICAL DESIGN

### 1. GENERAL CONFIGURATION

The general configuration of the TMXO has not changed from that described in the previous report (ECOM-75-1327-1). Some additional details are given here by means of two drawings. Figure 3 shows the TMXO cover (cap), and Figure 4 is a drawing of the machined header.

### 2. SEALING THE CRYSTAL ENCLOSURE

The crystal enclosure consists of a ring and two cover plates, all made out of nickel. The covers were soldered to the ring with a 96% tin - 4% silver solder (221°C), using a reflow technology. One of the covers had a small hole for evacuation and backfilling. The enclosure was outgassed at $5 \times 10^{-6}$ Torr for 40 hours at 150°C. It was then backfilled with nitrogen at about 10 Torr. The hole was sealed by solder reflow (96% tin - 4% silver) using a remotely controlled soldering iron tip in a vacuum system. To prevent any solder from striking the crystal, a copper foil baffle had been previously welded over the hole on the inside of the cover. A fixture to seal five crystal enclosures in a single pump down was used.

### 3. SEALING THE MICROCIRCUIT ENCLOSURE

This enclosure was sealed in vacuum. The cover had a hole and baffle similar to that of the crystal enclosure. The cover was soldered on, in air, using the 95% tin - 4% silver solder. The microcircuit enclosure was then placed in a vacuum chamber and out-gassed at $5 \times 10^{-6}$ Torr for 40 hours at 150°C. The evacuation hole was then sealed in the same manner as the crystal enclosure.

### 4. SOLDERING THE CRYSTAL AND MICROCIRCUIT ENCLOSURES TOGETHER

The crystal and microcircuit enclosures are soldered together so that there will be good heat transfer from the heater to the crystal. The sides without the sealing holes are first "tinned" with solder. The enclosures are then held together, reheated until the solder flows, and then cooled. Because of the solder temperature problems discussed in paragraph 5 of this section, a special solder was employed for this purpose. This solder is 55% tin - 45% lead. This is not a standard formulation, therefore, it was prepared in our laboratory from the pure elements. This solder has a solidus of 181°C and a liquidus of 205°C. At 185°C this solder shows no flowing tendency even with added liquid flux.

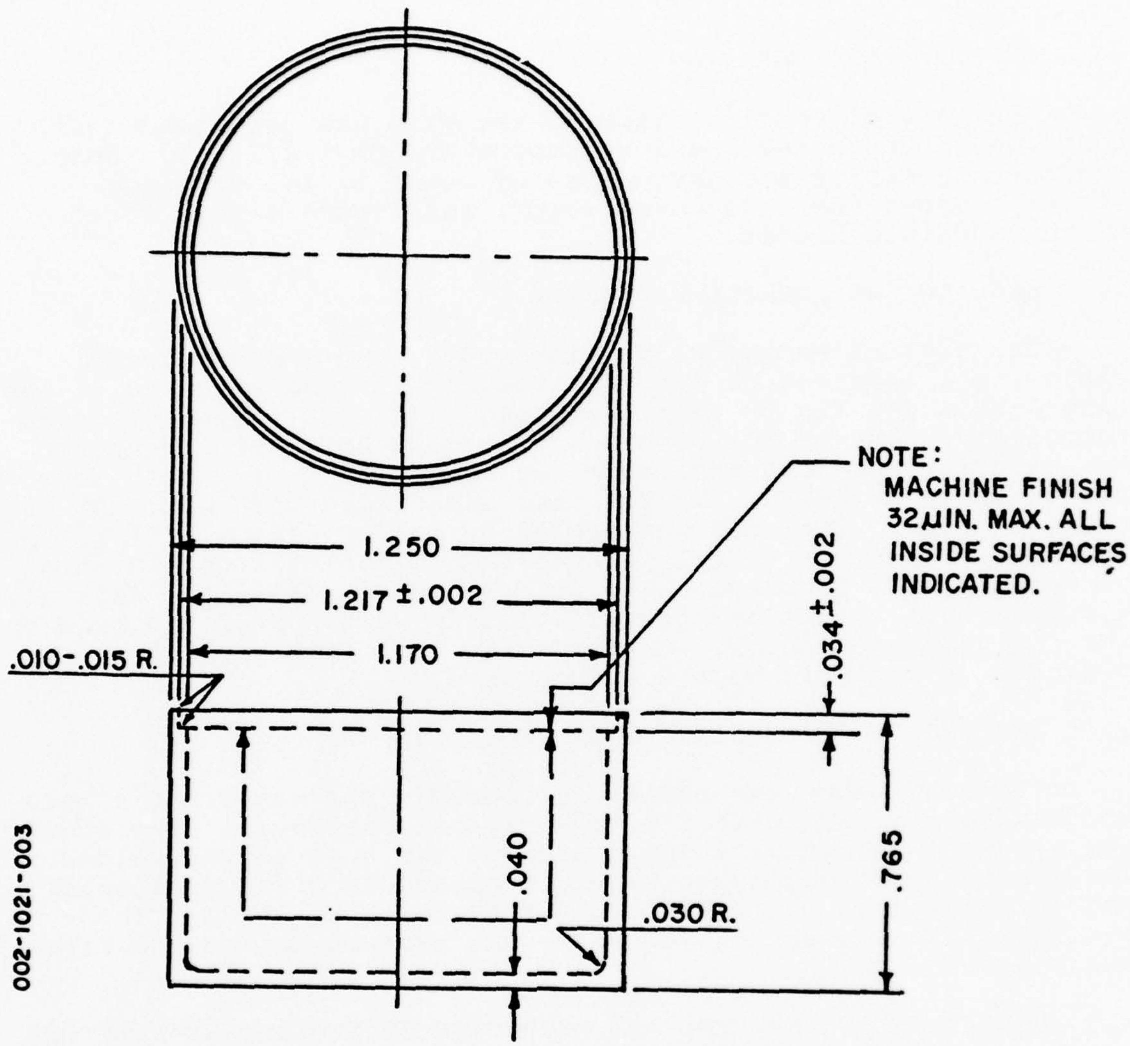



Figure 3. Cover of TMXO

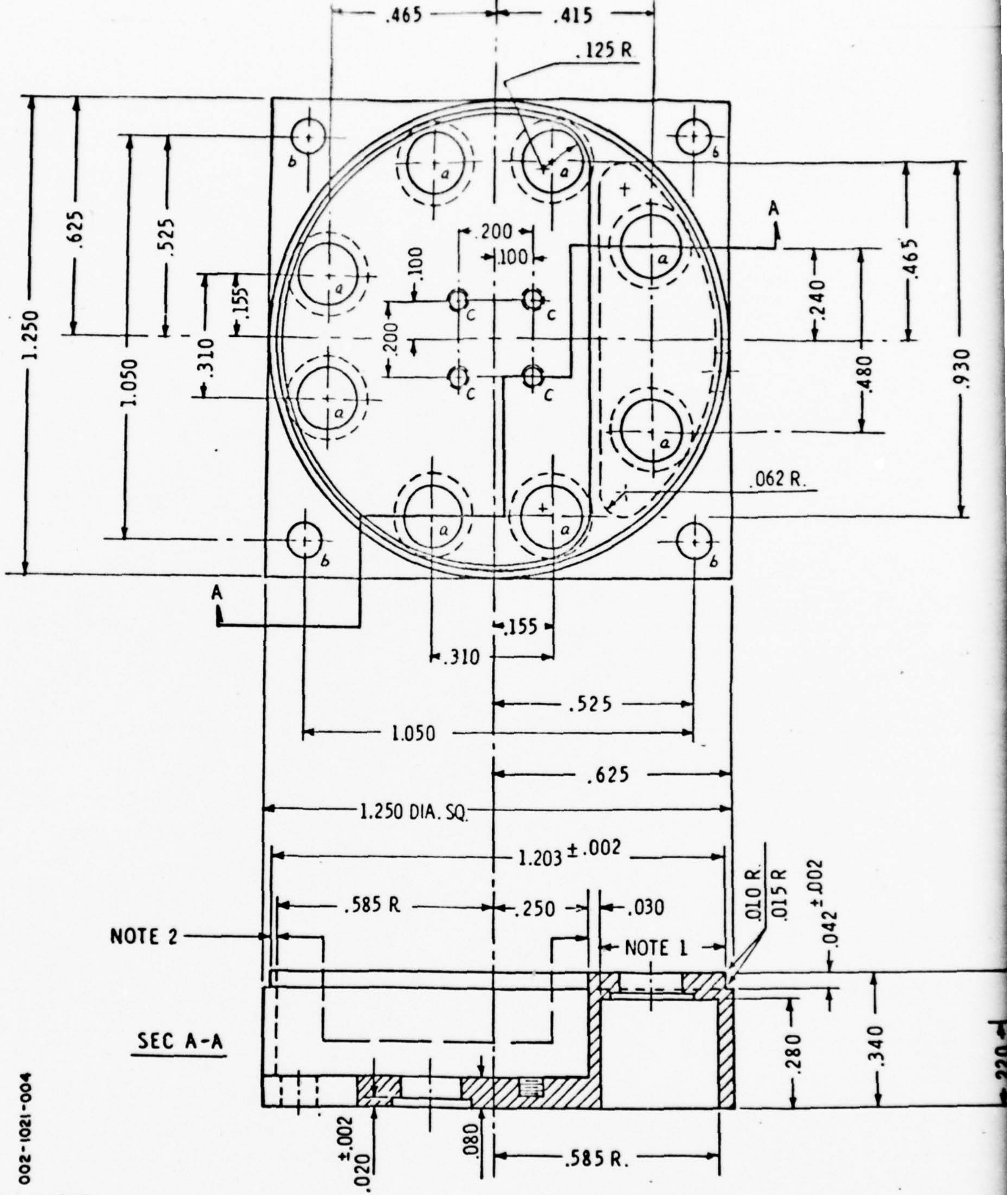



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Fig

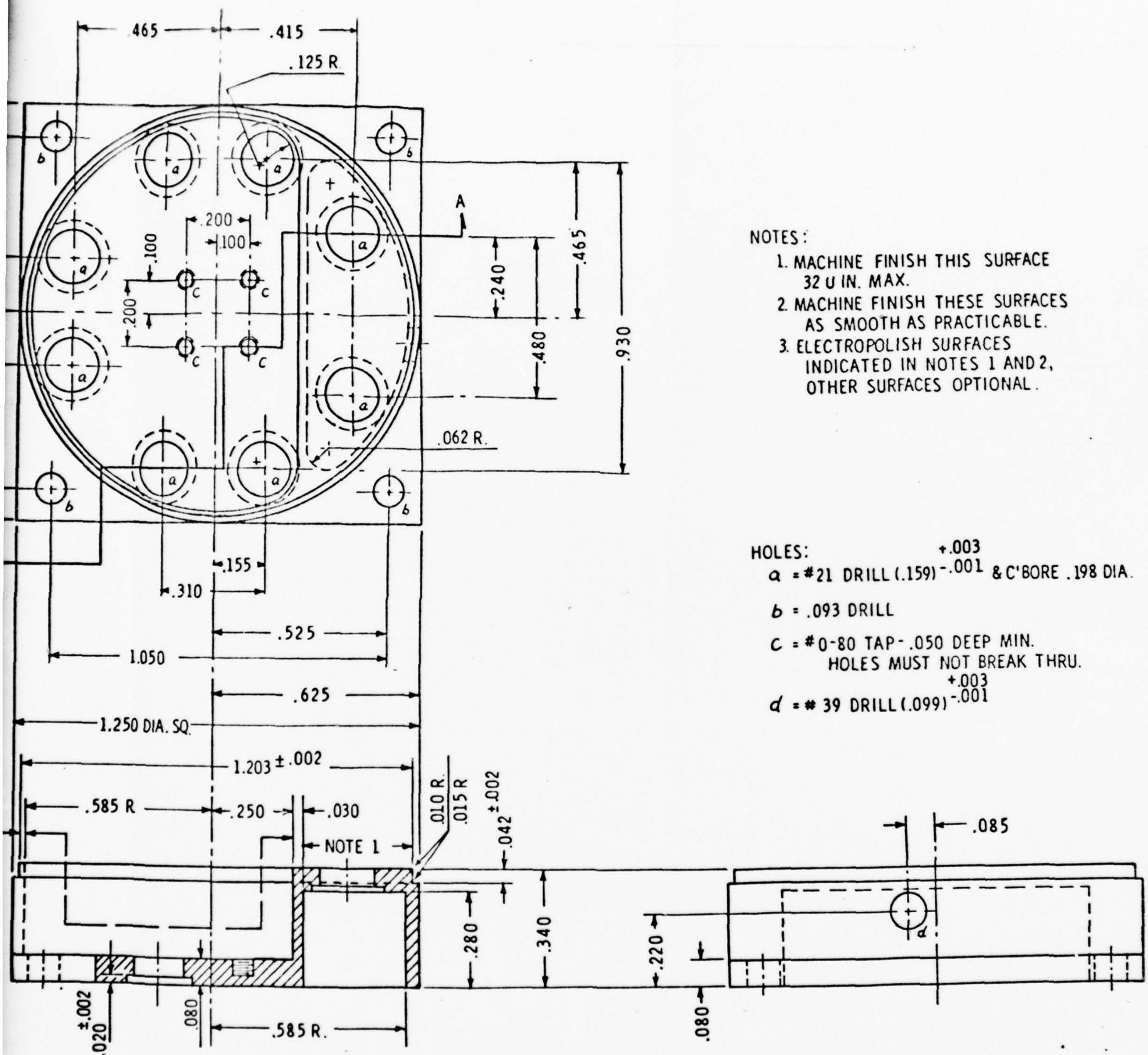


Figure 4. Machined Header of TMXO

5. SOLDER TEMPERATURE PROBLEMS

The improper selection of solders can lead to catastrophies. Such a catastrophe occurred when we originally chose the 60% tin - 40% lead solder (181°C eutectic) for joining the crystal enclosure to the microcircuit enclosure. When sealing the TMXO, this 181° solder flowed, coating the microcircuit enclosure and shorting out the oscillator. The TMXO was sealed with a 162°C eutectic, being heated to about 180°C to make the seal. The 181°C solder was changed as described in paragraph 4 of this section. The correct solders to use are indicated in Figure 5, Solder Flow Chart.

6. THE PEDESTAL

The thermal insulating pedestal remains the same as last reported. It is machined out of DuPont's polyimide VESPEL-SP-1. Thermal resistance of this pedestal is 1830°C/W. A drawing of the pedestal is shown in Figure 6.

7. SEALING THE TMXO

Sealing the TMXO enclosure required special fixturing for vacuum sealing the stainless steel TMXO case. It consisted of the following:

(a) An upper oven to outgas the TMXO cap just prior to final sealing.

(b) A lower oven to outgas the TMXO header, pedestal, crystal package, and microcircuit package just prior to sealing. This lower oven will also supply the heat to seal the TMXO.

(c) A remote controlled mechanism, which lowers the TMXO cap from the upper oven to the lower oven. To ensure a better seal it can also turn the cap during the solder reflow sealing.

(d) Several thermocouples to measure the temperature at various places.

The header and cap are pretinned with the 162°C eutectic solder. The TMXO is then assembled, tested, and placed in the sealing fixtures in the vacuum chamber. The unit is tested under vacuum conditions and then shut off. The header assembly is outgassed in the lower oven at 150°C and the cap is outgassed in the upper oven at 220°C. Both are at a pressure between $1 \times 10^{-5}$ and $5 \times 10^{-6}$ Torr for 90 hours. After the 90 hours, the temperature of the header is raised to 175°C, the cap is lowered, and the seal is made. The temperature at the seal at this time is 180°C.

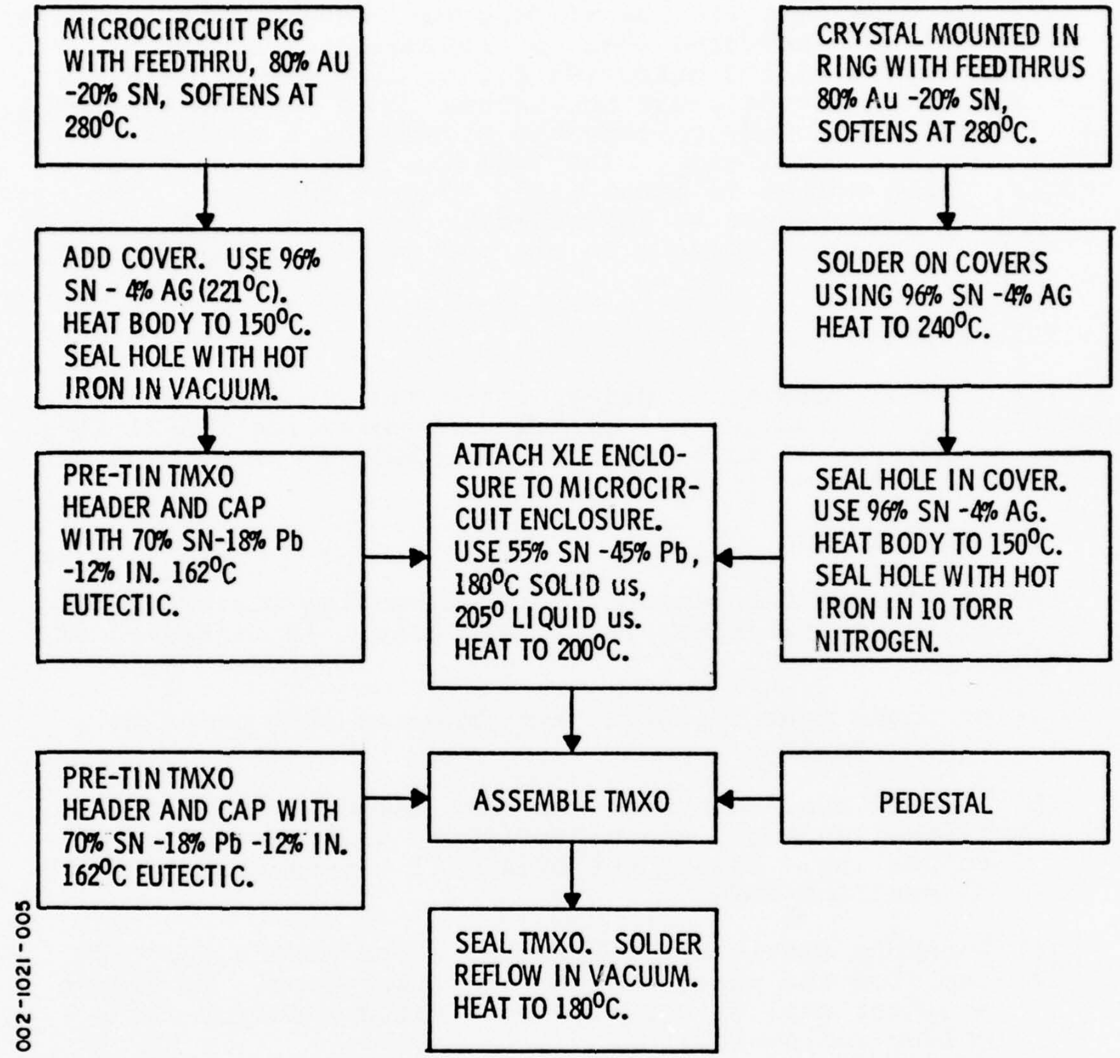


Figure 5. Solder Flow Chart

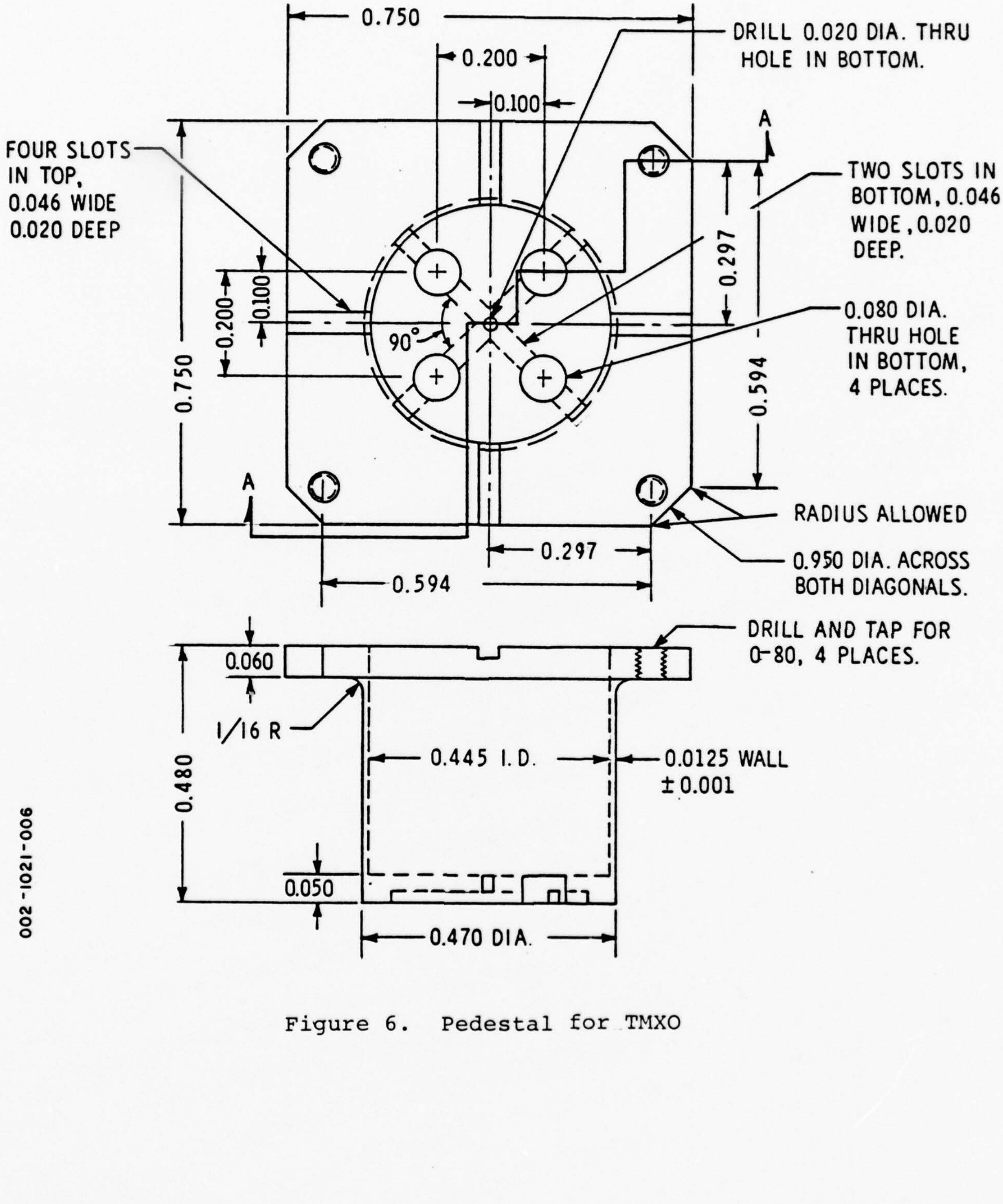


Figure 6. Pedestal for TMXO

## IV

## THE VACUUM PROBLEM

### 1. GENERAL

Maintaining a vacuum in the sealed TMXO is still a problem area. To show no degradation in power or performance for a period of one year, the pressure inside the TMXO must remain below $5 \times 10^{-4}$ Torr. If the pressure increased to $1 \times 10^{-3}$, the performance would be adequate, except for a few percent increase in power.

The pressure increase in the TMXO is primarily due to outgassing inside, or a leak in the TMXO package. A leak in the microcircuit or crystal enclosure is less of a problem, as the pressure inside these enclosures is two to three magnitudes below atmospheric pressure. What ever the source of the residual gases, the getter welded in the TMXO cover will absorb some percentage of these gases. Our experiments indicate that the pumping speed of the getter is greater than $4 \times 10^{-12}$ Torr-l/s mg. The getter consists of 110 mg of active mass, for a pumping speed greater than $110 \times 4 \times 10^{-12} = 4.4 \times 10^{-10}$ Torr l/s.

Therefore, if the outgassing and leak rate can be kept below this level, the TMXO will maintain its vacuum.

### 2. OUTGASSING

Experiments with a stainless steel pedestal in a stainless steel TMXO package have shown that the outgassing is below the getter's pumping speed (greater than $4.4 \times 10^{-10}$ Torr l/s). The pedestal and cap was outgassed for 96 hours at 400°C. The header was outgassed at 200°C for 96 hours. Just prior to sealing, the assembly was outgassed 40 hours at 150°C.

A similar experiement with a VESPEL pedestal resulted in a pressure rise in the TMXO package. A small leak in the TMXO package as well as insufficient outgassing of the pedestal was probably the cause. The pedestal had previously been outgassed as follows.

(a) 3 hours at 300°C in vacuum

(b) 24 hours at 350°C in air

(c) 40 hours at 400°C in vacuum.

Outgassing temperature of the microcircuit/crystal assembly is limited to 160°C because of construction materials.

3. LEAKS IN THE TMXO PACKAGE

The TMXO header contains eight metal/ceramic feedthroughs. This type of feedthrough did not leak when previously used. They had been vacuum brazed by the ECOM laboratory. In the present program, the brazing was done by a commercial company, in an argon atmosphere.

All feedthroughs were leak tested prior to sending them and the headers out for brazing. When the brazed parts were returned, the header was leak tested. A small percentage of the feedthroughs had small leaks. The headers were then vacuum outgassed at 400°C for 100 hours. The small leaks became larger and new small leaks were found.

Mostof the leaks were at the ceramic-pin interface and was probably due to rapid cooling after brazing. Insufficient time did allow procuring new feedthroughs, and reprocessing the headers. The leaks were repaired using a 80% gold - 20% tin solder (280°C). After this repair, a few small leaks (between $2 \times 10^{-9}$ and $2 \times 10^{-10}$ std cc/s) were found. These were eliminated by sealing with epoxy on the outside of the header. The possibility of the epoxy contributing to the outgassing inside the TMXO is almost nonexistent. The surface area of the epoxy exposed through such a small leak is infinitesimal.

4. PROCEDURE FOLLOWED IN THE DELIVERABLE MODELS

The various solder temperatures used in the fabrication of the TMXO, followed the solder flow chart shown in Figure 5.

The outgassing schedules for the various parts and assemblies were as follows.

<u>The TMXO cover</u>. Outgassed at $1 \times 10^{-5}$ Torr at 480°C for 96 hours. Electropolish. Outgass at $1 \times 10^{-5}$ Torr at 400°C for 96 hours.

<u>The TMXO header</u>. Before feedthroughs, outgassed at $1 \times 10^{-5}$ Torr at 480°C for 96 hours. Electropolish. Braze in feedthroughs. Outgas at $1 \times 10^{-5}$ Torr at 400°C for 96 hours. Repair leaks with 80% gold - 20% tin solder. Complete repair with epoxy. Outgas 100 hours at $1 \times 10^{-5}$ Torr and 180°C.

<u>The Vespel pedestal</u>. Bake in air at 350°C for 48 hours. Outgas at $1 \times 10^{-5}$ Torr for 96 hours at 400°C.

<u>The Microcircuit Package (without the microcircuit)</u>. Outgas at $1 \times 10^{-5}$ Torr for 96 hours at 180°C.

<u>The crystal enclosure ring and covers</u>. Outgas at $1 \times 10^{-5}$ Torr for 96 hours at 480°C.

The TMXO assembly just prior to sealing. Vacuum outgas at $1 \times 10^{-5}$ Torr at 150°C for 90 hours.

## V

## PERFORMANCE OF DELIVERED MODELS

Five engineering models were delivered. They were tested in accordance with the test set-ups shown in Figures 7, 8 and 9.

### 1. SETTING THE OPTIMUM CRYSTAL TEMPERATURE

When testing the unsealed TMXO both in air and in vacuum, the temperature was set to a nominal 90°C by a fixed resistor connected remotely from the TMXO across terminals 8 and 7. After sealing, while still in the vacuum chamber, the TMXO was briefly tested in the same manner. After removal from the vacuum chamber, the optimum crystal temperature was set.

Experience has shown that it takes less time to set this critical temperature if a resistance decade box is first used, and then replacing it with the potentiometer. Using the potentiometer only is very difficult because the value of the potentiometer at any setting is not known, it is difficult to keep track of the number of turns, and its linearity is unknown. The resistance decade box is connected across terminals 8 and 7, and set at 25 kΩ. In a temperature chamber at 25°C, the TMXO is turned on, and after a few minutes the resistance is changed until the frequency is near its minimum value. Lower the temperature to -40°C, set the resistance box so that the frequency is $2 \times 10^{-8}$ higher than it was at room temperature. Go back to room temperature and note the frequency. The -40°C to +25°C frequency change will probably be greater than $2 \times 10^{-8}$ of the last -40°C reading. Repeat the -40°C -25°C cycle. Change the temperature to +70°C, note the frequency. It should be greater than the room temperature value and be approximately equal to the -40°C value. If not, a resistance change at +70°C and at 25°C should be made. Set a potentiometer to the decaded resistance value and insert it in the base of the TMXO. Repeat the thermal cycling going from +25°C, -54°C, +75°C, +25°C, setting the temperature to optimize the frequency/temperature curve. Only a ± half turn of the potentiometer should be required.

### 2. OPERATING POWER

The operating power depends upon the degree of vacuum in the TMXO. The power was calculated from the input current measurement using set up No. 1. The input current is not a constant DC value, but is a current pulse whose amplitude, width, and period is a function of the ambient temperature. The setup shows the current being measured by a Weston milliampere meter and a Tektronix current probe. At times a Triplett (DC milliamperes) was used in place of the Weston meter. Both of these meters give the correct result of the average current. There is

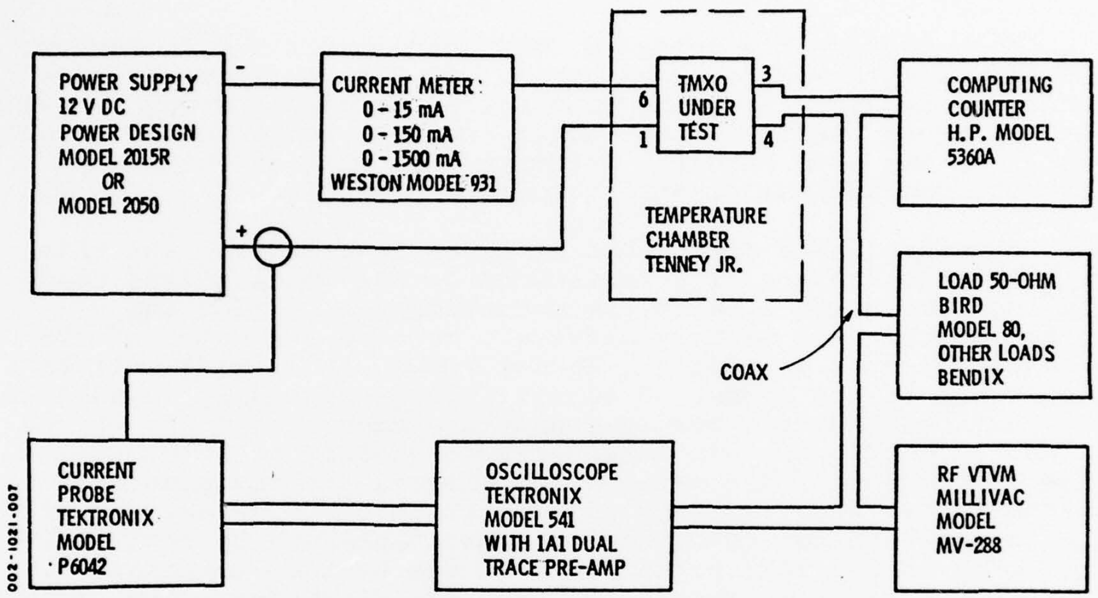


Figure 7. Test Setup No. 1

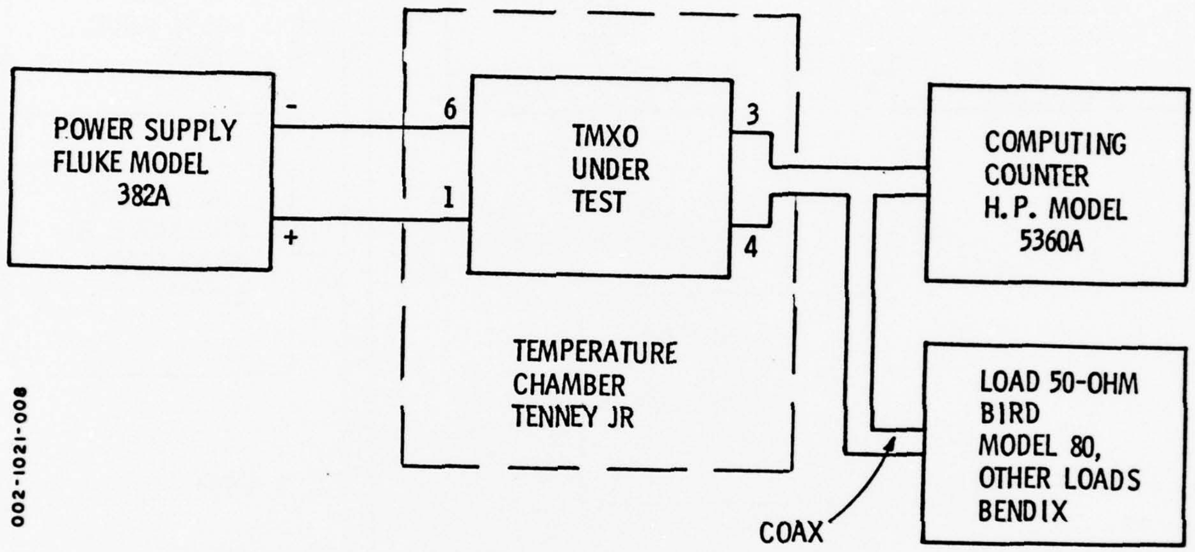


Figure 8. Test Setup No. 2

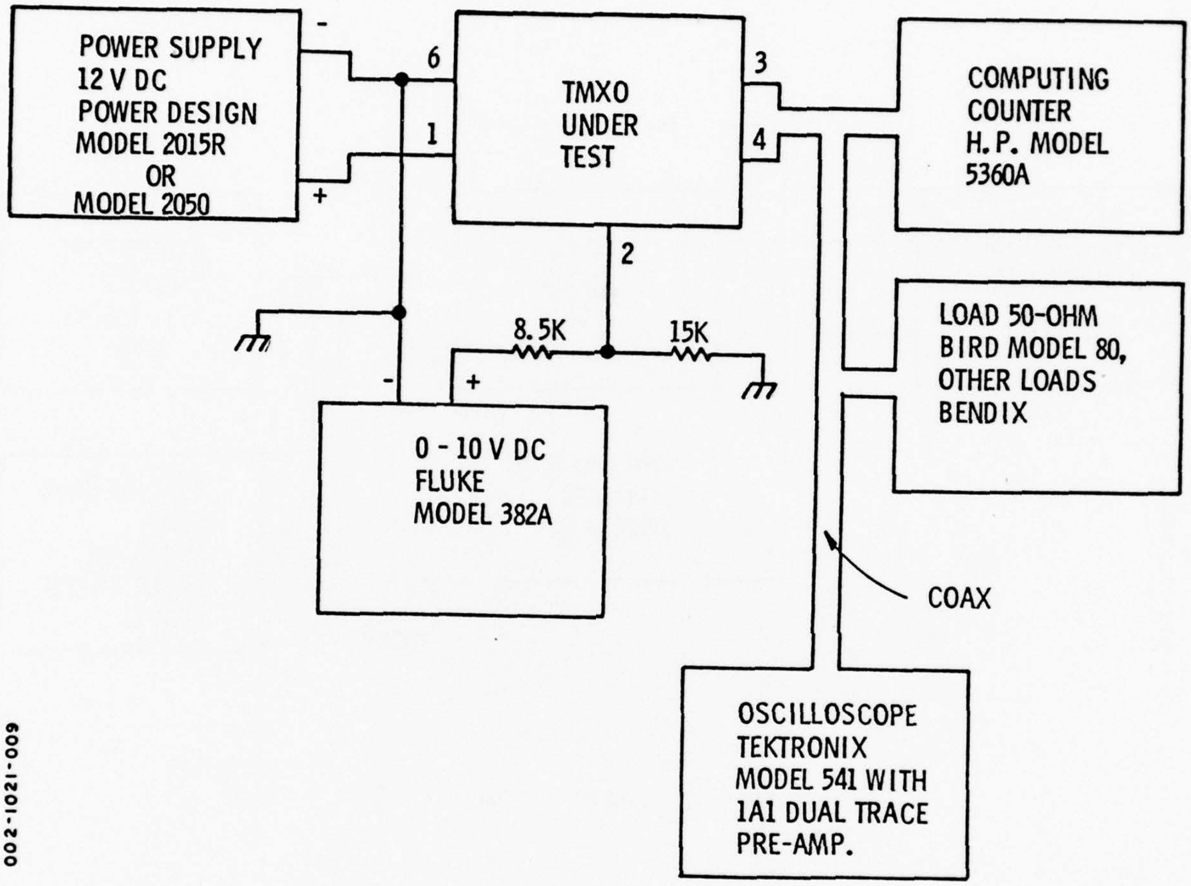


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Figure 9. Test Setup No. 3

an oscillation in the indicating needle due to the pulsing characteristic of the input current but the average reading is the average current.

The validity of the DC meter reading was proven by the current measurement using the current probe. The average current was calculated from the pulse measurement using the following equation:

$$I_{avg} = \frac{\text{Pulse amplitude (at 90\%)x Pulse with (at 50\%)}}{\text{Period}}$$

The operating powers for the models at various temperatures are.

TMXO No. 1

+25°C, 0.028 W
-40°C, 0.40 W
-54°C, 0.50 W
+75°C, 0.084 W

TMXO No. 2

+25°C, 0.56 W
-54°C, 1.20 W
+74°C, 0.17 W

TMXO No. 3

+25°C, 0.44 W
-40°C, 0.75 W
-54°C, 0.90 W
+67°C, 0.20 W

TMXO No. 4

25°C, 0.30 W

TMXO No. 5

25°C, 1.0 W

TMXO Nos. 4 and 5 had no RF output and only limited measurements were made on these units.

## 3. PEAK POWER

This is the input power at turn on. It is limited by current limiting resistors in the TMXO. The duration of this peak power is a function of the ambient temperature, varying from a few seconds at +75°C to about 80 seconds at -54°C. The peak power is measured using test setup No. 1 and is:

| | |
|---|---|
| TMXO No. 1 | 8.4 W |
| TMXO No. 2 | 7.8 W |
| TMXO No. 3 | 9.0 W |
| TMXO No. 4 | 9.0 W |
| TMXO No. 5 | 9.0 W |

## 4. VOLTAGE CONTROL

A voltage source of 0 to 10 VDC, in conjunction with two resistors (85 kΩ and 15 kΩ), will result in a fine frequency adjustment. The test setup for this measurement is shown in Figure 9. The frequency range in response to this voltage control for the various models is as follows.

| | |
|---|---|
| Model No. 1 | $3.2 \times 10^{-7}$ |
| Model No. 2 | $3.2 \times 10^{-7}$ |
| Model No. 3 | $2.9 \times 10^{-7}$ |
| Model No. 4 | No RF output |
| Model No. 5 | No RF output |

The control voltage/frequency curve can be seen in Figure 10.

## 5. FINE FREQUENCY ADJUSTMENT

The fine frequency adjustment is accomplished with a ten turn 100 kΩ potentiometer. The center of the tuning range occurs at about 22 kΩ. The tuning range for the models was.

| | |
|---|---|
| Model No. 1 | $4.4 \times 10^{-7}$ |
| Model No. 2 | $4.4 \times 10^{-7}$ |
| Model No. 3 | $4.0 \times 10^{-7}$ |
| Model No. 4 | No RF output |
| Model No. 5 | No RF output |

The frequency could be set to better than $\pm 3 \times 10^{-10}$, which was the resolution of the test setup. This setup is shown in Figure 8.

## 6. FREQUENCY/TEMPERATURE STABILITY (STEADY STATE)

The steady state frequency/temperature characteristics, over an ambient temperature range of -55°C to +75°C, is plotted in Figures 11, 12 and 13 for Models 1, 2 and 3. No data is available for Models 4 and 5, as they had no RF output. Model No. 1 had a good vacuum and its frequency change over the temperature range was only $\pm 4 \times 10^{-9}$. Models 2 and 3 had poor vacuums and their frequency change was $\pm 7 \times 10^{-8}$ and $\pm 1.05 \times 10^{-7}$ respectively. The test setup to make these measurements is shown in Figure 7.

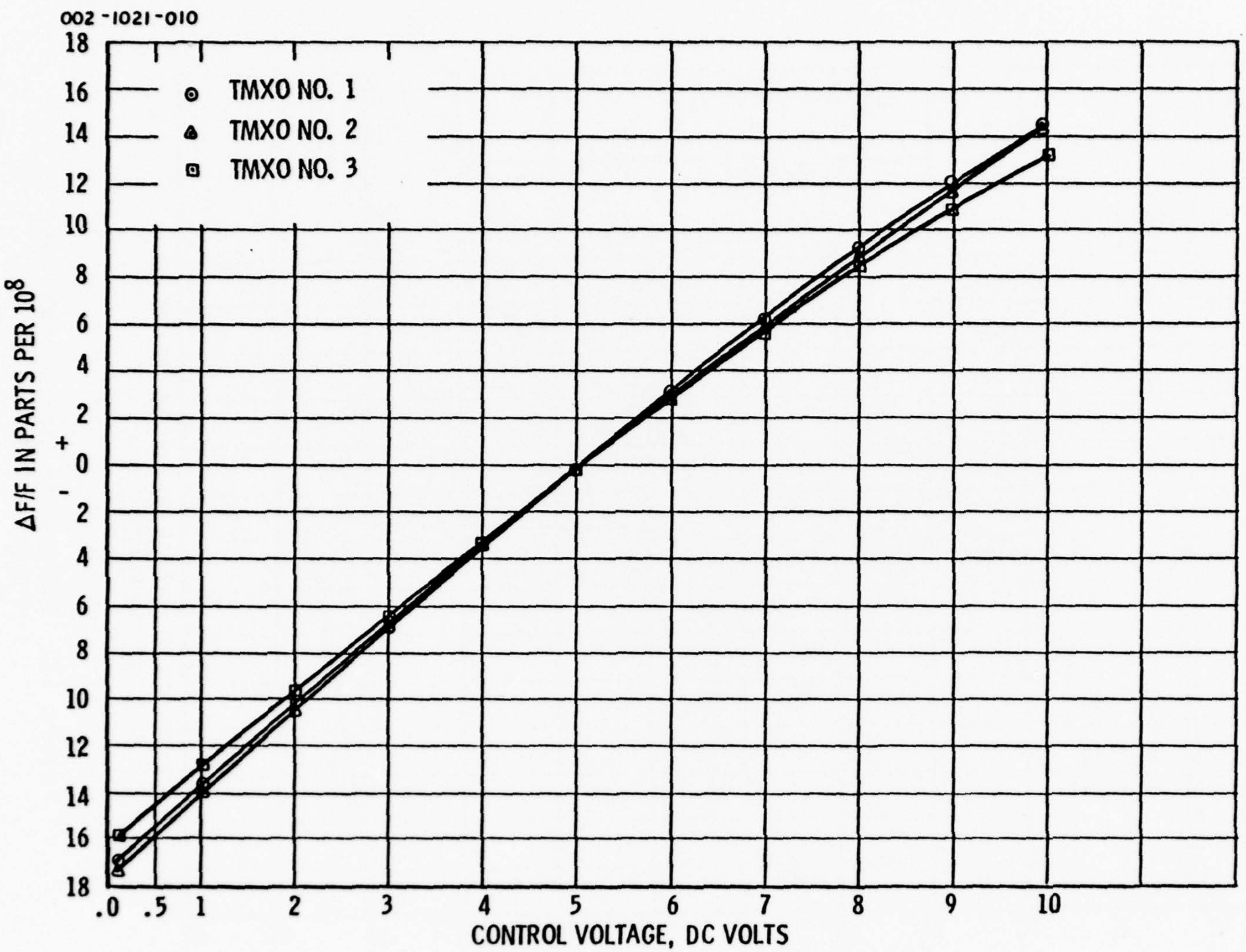


Figure 10. Control Voltage Versus Frequency

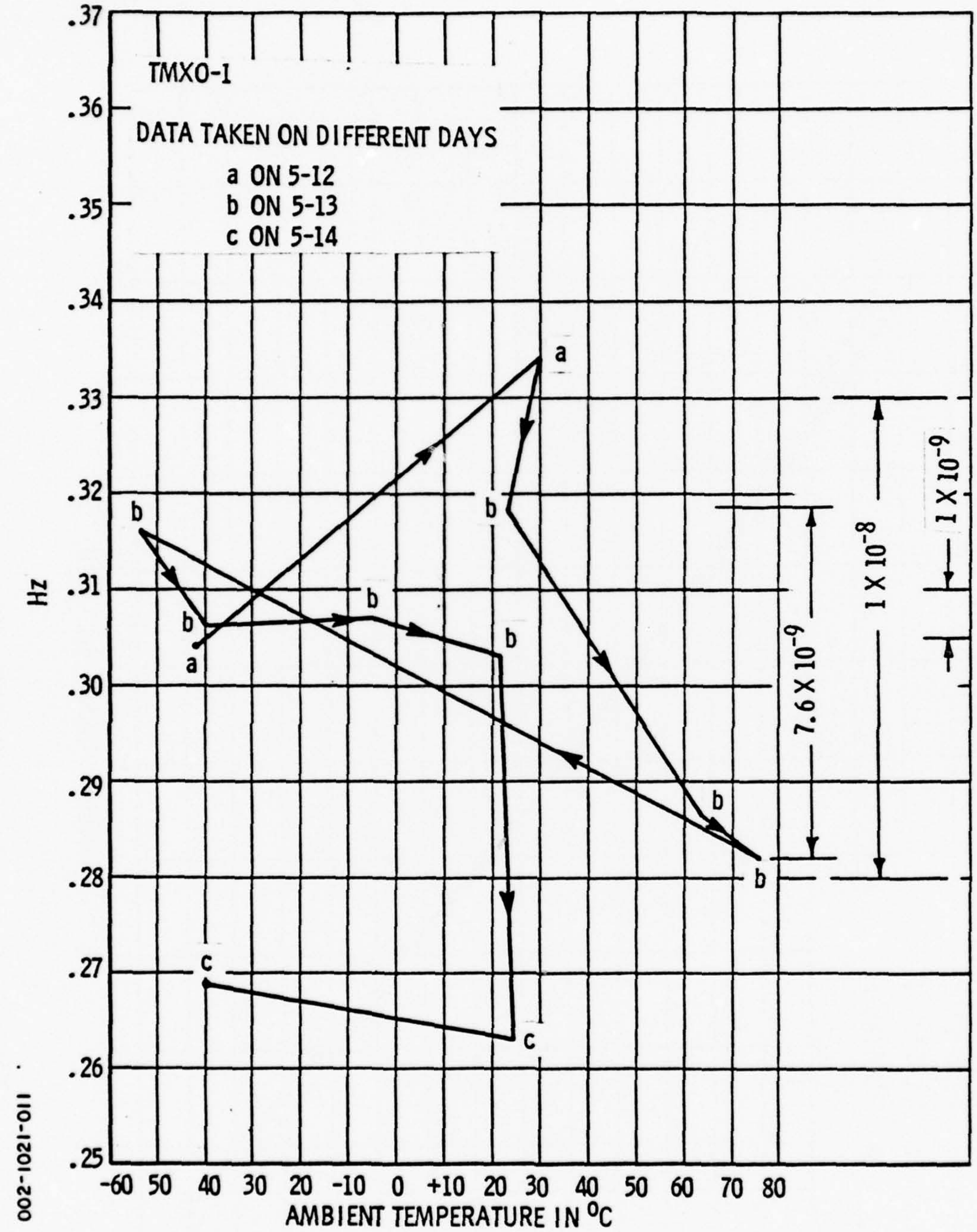


Figure 11. Frequency Versus Ambient Temperature for TMXO-1

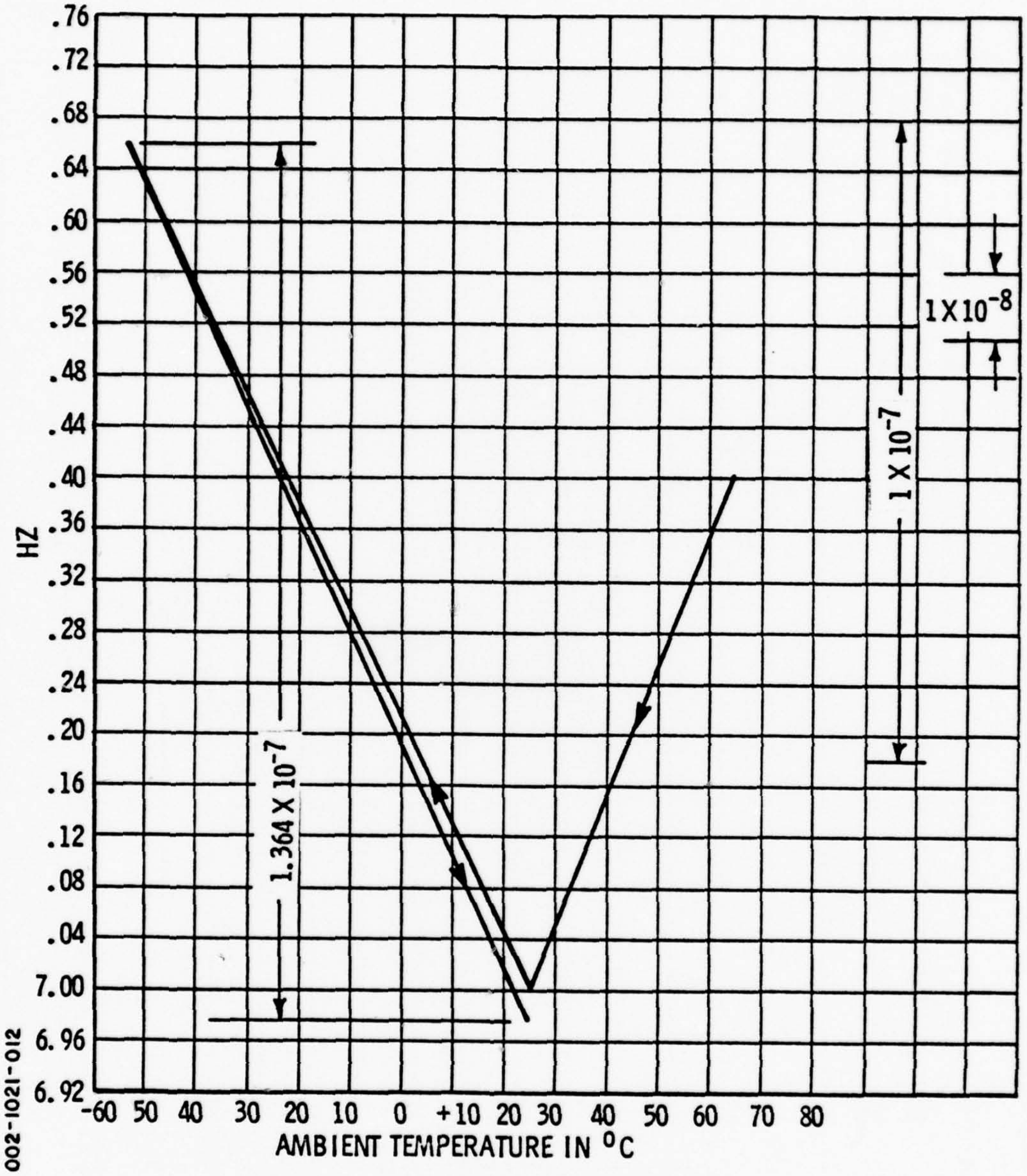


Figure 12. Frequency Versus Ambient Temperature for TMXO-2

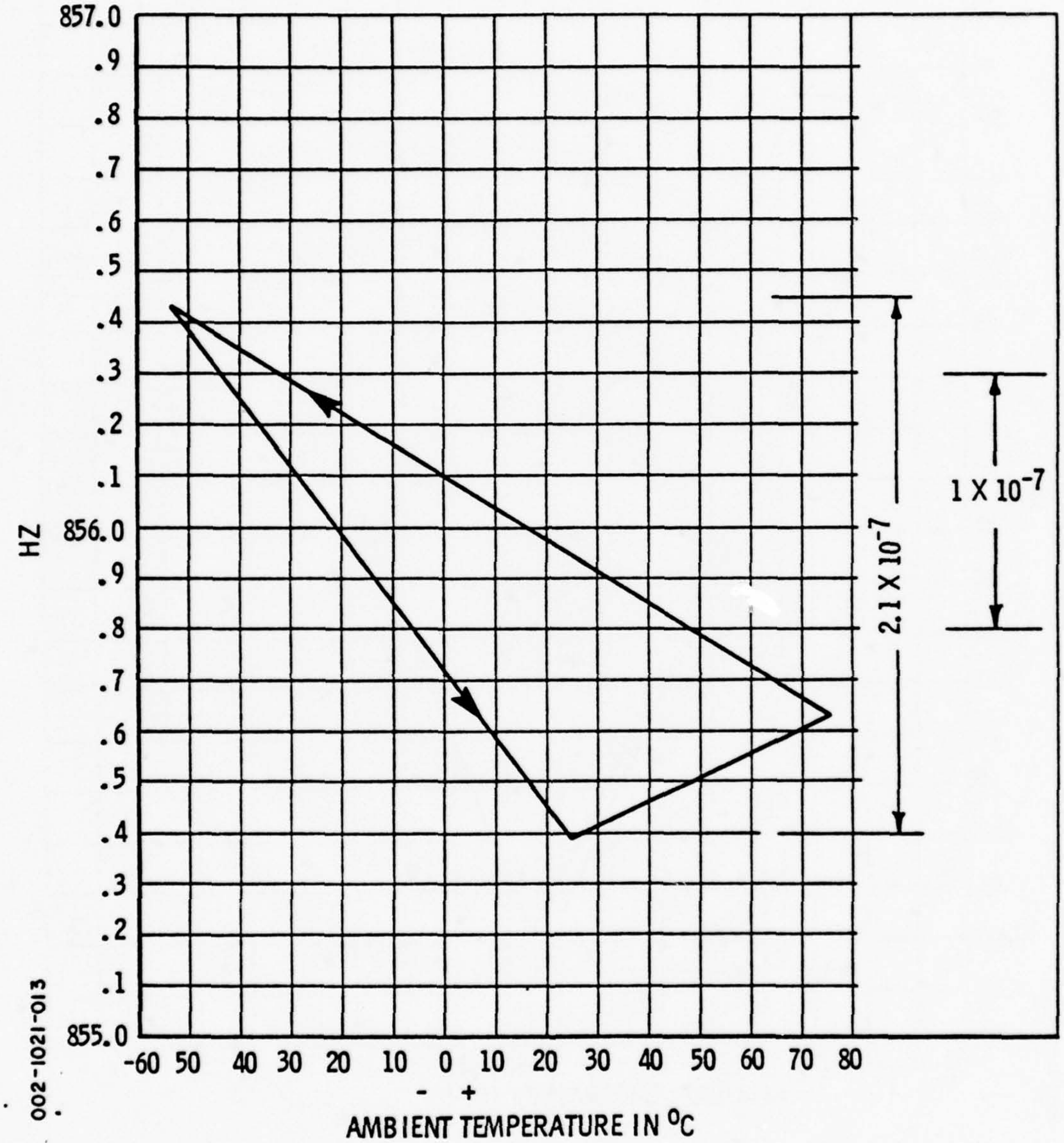


Figure 13. Frequency Versus Ambient Temperature for TMXO-3

7. FREQUENCY/TEMPERATURE STABILITY (TRANSIENT)

The frequency should not be sensitive to transient temperatures. The maximum allowable frequency change is $\pm 1 \times 10^{-8}$ when subjected to a positive 10°C amplitude at a rate of $\leq$ 1°C/min, starting from -40°C, -5°C, +30°C, and +65°C. This parameter was measured for Model No. 1 with the following results.

| Starting Temperature | Temperature Ramp Rate | Maximum ΔF/F |
|---|---|---|
| -40°C | 6.7°C/min | $-2.8 \times 10^{-9}$ |
| -5°C | 6.7°C/min | $-3.8 \times 10^{-9}$ |
| +30°C | 7°C/min | $-5.2 \times 10^{-9}$ |
| +65°C | 4.4°C/min | $-5.2 \times 10^{-9}$ |

The test setup is shown in Figure 7.

8. FREQUENCY/LOAD STABILITY

The change in frequency with a change in load was measured using the test setup shown in Figure 8. The measured values are given in the following table.

| TMXO No. | Load | ΔF/F |
|---|---|---|
| 1 | 56Ω + 20°ϕ | $-2.1 \times 10^{-9}$ |
| 1 | 56Ω - 20°ϕ | $+2.8 \times 10^{-9}$ |
| 1 | 44Ω + 20°ϕ | $-1.2 \times 10^{-9}$ |
| 1 | 44Ω - 20°ϕ | $+2.0 \times 10^{-10}$ |
| 3 | 56Ω + 20°ϕ | $-1.4 \times 10^{-9}$ |
| 3 | 56Ω - 20°ϕ | $+4.2 \times 10^{-9}$ |
| 3 | 44Ω + 20°ϕ | $-1.4 \times 10^{-9}$ |
| 3 | 44Ω - 20°ϕ | $+3.6 \times 10^{-9}$ |

9. FREQUENCY/POWER SUPPLY VOLTAGE STABILITY

The change in frequency due to a change of ±5% in the power supply voltage was measured with the test setup shown in Figure 8. The measured data is tabulated below.

| TMXO No. | Power Supply Voltage Change | $\Delta F/F$ |
|---|---|---|
| 1 | +5% | $-3 \times 10^{-9}$ |
| 1 | -5% | $+2 \times 10^{-9}$ |
| 3 | +5% | $\pm 3 \times 10^{-10}$ |
| 3 | -5% | $-8 \times 10^{-10}$ |

## 10. SHORT TERM STABILITY

The short term stability was measured using the test setup shown in Figure 8. Peak frequency deviation readings were taken on the computing counter having an error of $\pm 3 \times 10^{-10}$. The averaging time was 1 second and readings were taken over a time period of 20 minutes.

Results were as follows.

Model No. 1: Better than $\pm 3 \times 10^{-10}$ peak-to-peak, corresponding to an RMX value of approximately better than $\pm 3 \times 10^{-11}$

Model No. 2: $\pm 2 \times 10^{-8}$ peak-to-peak, corresponding to an RMS value of approximately $\pm 2 \times 10^{-9}$

Model No. 3: $\pm 1.2 \times 10^{-9}$ peak-to-peak, corresponding to an RMS value of approximately $\pm 1.2 \times 10^{-10}$

The high noise in Models 2 and 3 was due to noise on the input pulse to the TMXO.

## 11. FREQUENCY/ATTITUDE STABILITY

This is a measurement of the change in frequency when the orientation of the TMXO is changed relative to the ground. This measures the effect of the gravitational force on the TMXO frequency. Measurements were made on Model No. 1. For a 90 degree change in attitude, the frequency deviation was less than $\pm 3 \times 10^{-10}$. For an attitude change of 180 degrees ($\Delta 2G$), the frequency deviation was $8 \times 10^{-10}$ or $4 \times 10^{-10}/G$.

## 12. STABILIZATION TIME

From turn on, the time needed for the frequency to be within $1 \times 10^{-8}$ of the final frequency was measured using the setup as shown in Figure 7. The warmup curves from various ambient temperatures are plotted in Figures 14, 15, and 16.

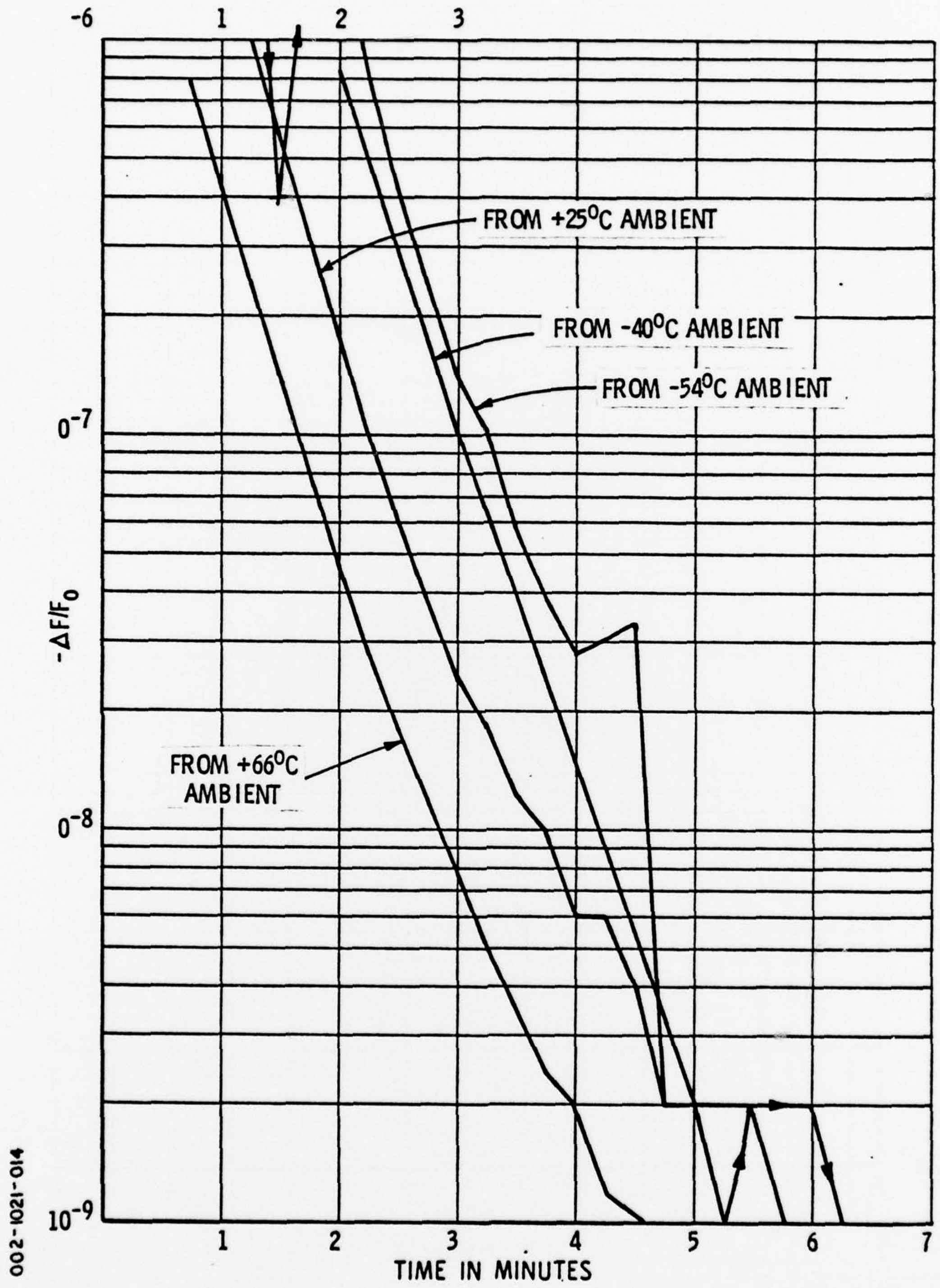


Figure 14. Warmup of TMXO No. 1

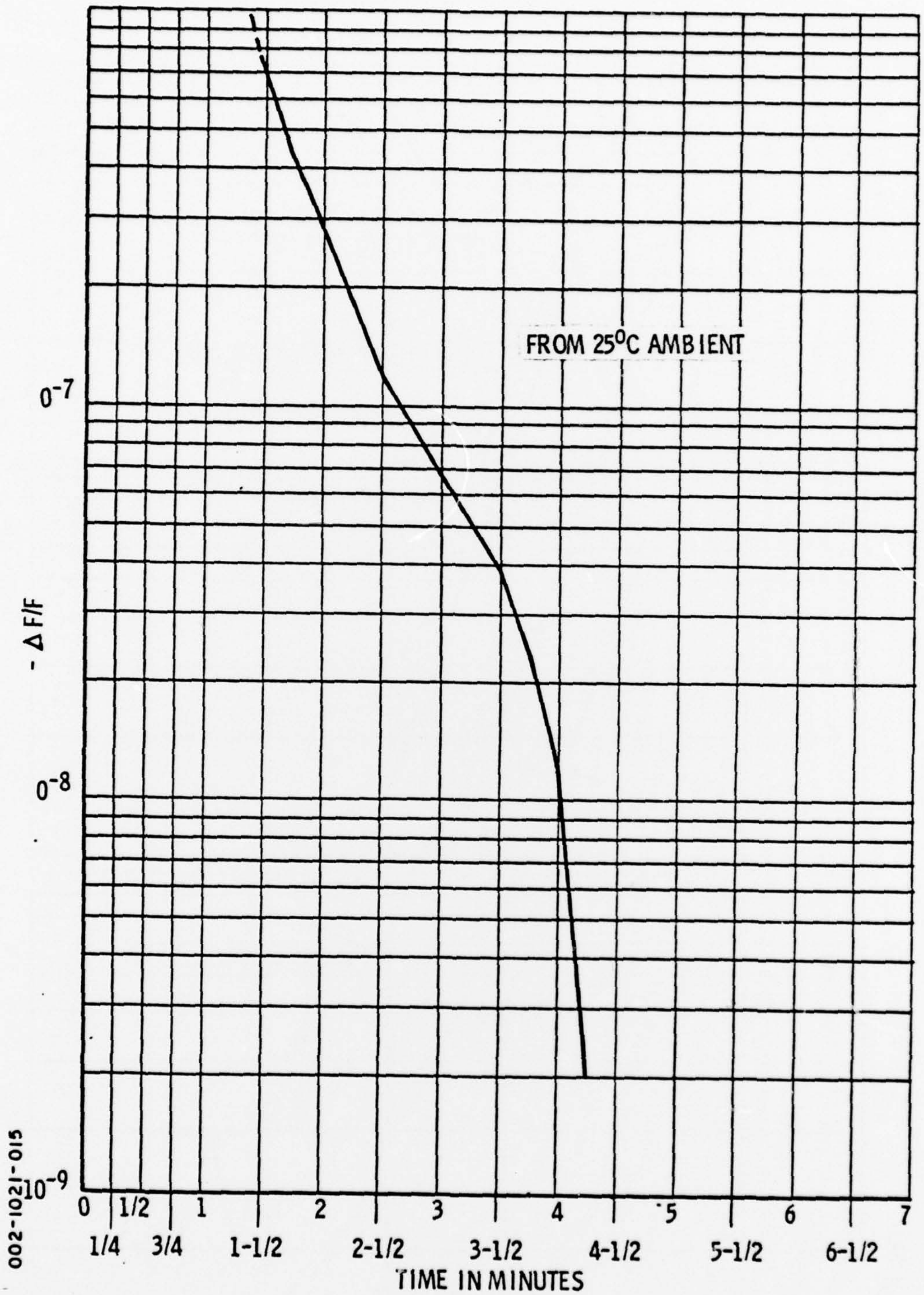


Figure 15. Warmup of TMXO No. 2

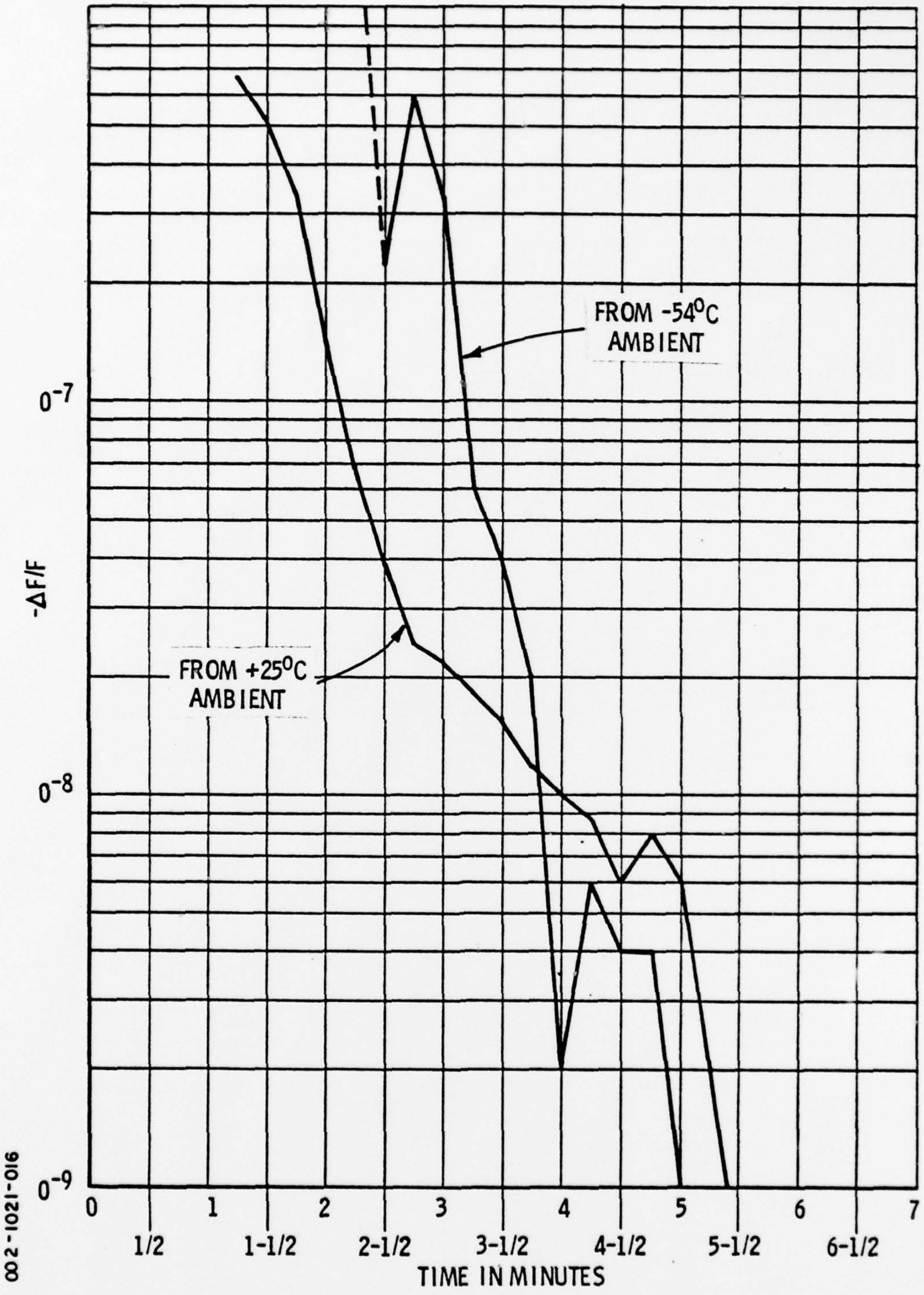


Figure 16. Warmup of TMXO No. 3

13. FREQUENCY RECOVERY AT -40°C

The ability of the TMXO to return to the same frequency after being in the off condition is an important stability parameter. The TMXO was maintained at an ambient temperature of -40°C. It was then subjected to five on-off cycles, each off cycle being at least 30 minutes. The maximum frequency deviation was $\pm 5 \times 10^{-8}$. As in previous measurements on earlier TMXOs, this change in frequency seems to be crystal dependent. There also seems to be two superimposed effects. One is a slow continuous hysteresis phenomenon while the other is a step change.

14. OUTPUT VOLTAGE

The minimum output voltage requirement of 0.125 volts RMS into 50 ohms was easily satisfied. The values for the TMXO models ranged from 0.148 volts to 0.28 volts.

# VI

# CONCLUSIONS

This TMXO program is directed at producing an ultrastable frequency source. The TMXO requirements allows a frequency variation of $\pm 2 \times 10^{-8}$ for all specified conditions simultaneously, as well as being compatible with other requirements. These other requirements have to do with size, power and warmup characteristics.

The frequency deviation budget (compiled from Section I of this report) is as follows.

| | Parameter | Allowed Frequency Deviation |
|---|---|---|
| (a) | Ambient Temperature, -54°C to +75°C | $\pm 1 \times 10^{-8}$ |
| (b) | Change in Power Supply Voltage | $\pm 1 \times 10^{-9}$ |
| (c) | Change in Load | $\pm 1 \times 10^{-9}$ |
| (d) | Acceleration, 1G | $5 \times 10^{-10}$ |
| (e) | Vibration | $\pm 1 \times 10^{-9}$ |
| (f) | Mechanical Shock | $\pm 1 \times 10^{-9}$ |
| (g) | Attitude | $5 \times 10^{-10}$ |
| (h) | Altitude | $\pm 1 \times 10^{-9}$ |
| (i) | Frequency Recovery | $\pm 3 \times 10^{-9}$ |
| (j) | Aging | $2 \times 10^{-10}$/wk |

The above parameters can be divided into groups.

| Group Parameter | Allowed Frequency Deviation |
|---|---|
| Ambient Temperature - 54°C to +75°C | $\pm 1 \times 10^{-8}$ |
| Electrical Environment (b and c) | $\pm 2 \times 10^{-9}$ |
| Mechanical Environment (d, e, f, g and h) | $\pm 4 \times 10^{-9}$ |
| Frequency Recovery | $\pm 3 \times 10^{-9}$ |
| Aging | $2 \times 10^{-10}$/wk |

Model No. 1, which had the best vacuum, had the best TMXO characteristics. Assuming a TMXO with a good vacuum, the following performance deficiencies (relative to the above group parameters) still exist. Frequency deviation due to the electrical environment is $\pm 6 \times 10^{-9}$. Frequency recovery deviation is $\pm 5 \times 10^{-8}$. Frequency changes due to aging are two orders of magnitude greater than required.

The frequency/temperature requirement was easily met. Measurements to date do not indicate any problem in the mechanical environmental areas.

Several problems remain, some are major, while others can be considered minor. The major problems are; vacuum, frequency recovery, quality of the crystal, and more reliable construction.

Model No. 1 had a sufficient vacuum, permitting excellent frequency/temperature characteristics both under steady state and transient conditions. However, the vacuum was not as good as expected, resulting in an operating power at -54°C of 0.5 watts instead of the expected value of 0.3 watts. Although the 0.5 watts may be suitable for most TMXO applications, the other models were not that good. The primary cause of the poor vacuum is leaks through the seals in the outer case. Better construction techniques are needed in fabricating the outer case. Secondary causes of the poor vacuum may be some leakage from the crystal and/or microcircuit enclosures. Going to ceramic packages for both of these may help the vacuum problem.

It is expected that the new ceramic crystal enclosure and crystal will greatly help the frequency recovery problem. It is not presently known if the circuitry contributes to this problem. With a better crystal, the circuitry recovery can be evaluated. If a circuitry problem is found, it most likely can be eleiminated by thermal cycling.

The new crystal in the ceramic enclosure will not only help the frequency recovery, it should give better stability with time, and much improved long term aging.

The present TMXO models were constructed using the "chip and wire" technology and with crystals assembled in our laboratory. Several failures were experienced due to these non-production-like techniques. The new crystal/enclosure should eliminate any crystal failures. It is recommended that the construction technique be changed to "thick film hybrid". With these two changes, the reliability of the TMXO should greatly improve.

Several minor problems exist, one onld, and some new. The old problem is the change in frequency with load and voltage. The present frequency variation is $\pm 3 \times 10^{-9}$ for either load or supply voltage. It is recommended that the circuit be modified to give better isolation.

Q10 of the present circuit is a CNCL05, a FET current limiting device, manufactured by Siliconix. This chip is no longer available and a replacement must be found. This is not a serious problem as several similar devices are available.

The other new problem is noise on the input current pulse. This noise causes a control temperature variation which results in frequency variations. The input to the TMXO being a low duty cycle pulsed current, any noise is amplified by a factor inversely proportional to the duty cycle. It is recommended that the input be changed to steady state, and the noise be eliminated. This will require some redesign of the heater circuit.

## VII

## FUTURE PLANS

To overcome the present deficiencies and solve the remaining problems, the following is planned for the continuance of this contract.

(a) Electrical Redesign

To eliminate the noise on the imput current pulse, the heater circuit will be redesigned for steady state operation. To improve the frequency/voltage stability, the coarse varactor will be replaced with a tapped capacitor. Better isolation will be incorporated to enhance the frequency/load characteristics. The circuit will be modified so that it will operate with a 10 MHz fundamental and a 10 mHz third overtone, as well as with the 5.115 MHz fundamental. A replacement for Q10 will be found to replace the part which is no longer made.

(b) Mechanical Redesign

The construction of the circuitry will be converted to the thick film hybrid technology. The same layout will be used for the three crystal types. The microcircuit will be enclosed in a ceramic package having fired-in feedthroughs. The outside package will be changed to a design similar to one now in production for a vacuum application. The outside package will be fabricated by the company who now has this similar design in production. This new outside package should solve the vacuum problem. The next models will use the newly developed ceramic crystal package. This crystal should yield better aging units, as well as improve the TMXO thermal retrace for on-off cycling from -40°C.

Five models will be delivered with these new changes.

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